

**EVALUATION AND SEED PRODUCTION
POTENTIAL OF EUROPEAN GENOTYPES OF
CARROT (*Daucus carota* L.) UNDER DIFFERENT
AGROCLIMATIC CONDITIONS OF PUNJAB**

Thesis

**Submitted to the Punjab Agricultural University
in partial fulfillment of the requirements
for the degree of**

**MASTER OF SCIENCE
in
VEGETABLE SCIENCE
(Minor Subject: Plant Breeding and Genetics)**

By

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(L-2017-A-163-M)**

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CERTIFICATE I

This is to certify that the thesis entitled “**Evaluation and seed production potential of European genotypes of carrot (*Daucus carota* L.) under different agroclimatic conditions of Punjab**” submitted for the degree of **Master of Science**, in the subject of **Vegetable Science** (Minor subject: **Plant Breeding and Genetics**) of the Punjab Agricultural University, Ludhiana, is a bonafide research work carried out by **Ms. Karamvir Kaur (L-2017-A-163-M)** under my supervision and that no part of this thesis has been submitted for any other degree.

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

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CERTIFICATE – II

This is to certify that the thesis entitled, “**Evaluation and seed production potential of European genotypes of carrot (*Daucus carota* L.) under different agroclimatic conditions of Punjab**” submitted by **Ms. Karamvir Kaur** (Admn. No. **L-2017-A-163-M**) to the Punjab Agricultural University, Ludhiana, in partial fulfillment of the requirements for the degree of **M.Sc.** in the subject of **Vegetable Science** (Minor subject: **Plant Breeding and Genetics**) has been approved by the Student’s Advisory Committee along with External Examiner after an oral examination on the same.

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ABSTRACT

The investigation entitled “Evaluation and seed production potential of European genotypes of carrot (*Daucus carota* L.) under different agroclimatic conditions of Punjab ” was carried out at Research Farm (Director Seeds), Punjab Agricultural University, Ludhiana (L1) and KVK Langroya, Shaheed Bhagat Singh Nagar (L2). Diverse European carrot genotypes were characterized by morphological, biochemical and seed production potential during 2018-19. Analysis of variance showed significant differences for quantitative traits with respect to locations, dates of sowing and genotypes. GGE Biplot model was used to produce biplot graphs which display the variability of genotypes and G×E interactions and visualized the stable performance of genotypes for all the quantitative and qualitative characters. Morphological, biochemical and seed production potential of European carrot genotypes were best in second location (KVK, Langroya). Mean values of morphological characters like root length, root weight, root girth and total root yield (kg/plot) was significantly maximum of genotypes *viz.*, Carrot Nantes, P-35, P-41 and Carrot Early Nantes when sown in first week of November. The genotypes such as P-35, P-5, Arka Suraj and P-16 showed significantly higher values in terms of total soluble solids, carotene content and sugar content. The genotypes Carrot Nantes, PCO-4, PCO-6 have significantly higher seed quality and seed production potential when sown in first week of January.

Key words: Agroclimatic, biochemical, carrot, GGE Biplot, genotypes, morphological

Signature of Major Advisor

Signature of the Student

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ਇਹ ਅਧਿਐਨ ਜਿਸ ਦਾ ਨਾਮ "ਪੰਜਾਬ ਦੇ ਅਲੱਗ-ਅਲੱਗ ਜਲਵਾਯੂ ਹਾਲਾਤਾਂ ਵਿੱਚ ਗਾਜਰ ਦੇ ਯੂਰੋਪੀਅਨ ਜੀਨੋਟਾਈਪ ਦਾ ਮੁਲਾਂਕਣ ਅਤੇ ਬੀਜ ਪੈਦਾ ਕਰਨ ਦੀ ਸਮਰੱਥਾ", ਪੰਜਾਬ ਐਗਰੀਕਲਚਰਲ ਯੂਨੀਵਰਸਿਟੀ, ਲੁਧਿਆਣਾ ਦੇ ਖੋਜ ਫਾਰਮ ਨਿਰਦੇਸ਼ਕ ਬੀਜ (L1) ਤੇ ਕੀ.ਵੀ.ਕੇ. ਲੰਗੜੋਆ, ਸ਼ਹੀਦ ਭਗਤ ਸਿੰਘ ਨਗਰ (L2) ਵਿੱਚ ਕੀਤਾ ਗਿਆ। 2018-19 ਦੌਰਾਨ ਯੂਰੋਪੀਅਨ ਗਾਜਰ ਦੇ ਵਿਭਿੰਨ ਜੀਨੋਟਾਈਪਾਂ ਦਾ ਰੂਪ-ਰੇਖਾ, ਜੈਵ ਰਸਾਇਣਕ ਅਤੇ ਬੀਜ ਪੈਦਾ ਕਰਨ ਦੀ ਸਮਰੱਥਾ ਆਦਿ ਨਾਲ ਵਰਨਣ ਕੀਤਾ ਗਿਆ। ਵਿਭਿੰਨਤਾ ਦੇ ਵਿਸ਼ਲੇਸ਼ਣ ਦਾ ਗਿਣਾਤਮਕ ਗੁਣਾਂ ਦਾ ਜਗ੍ਹਾ, ਬੀਜਣ ਦੀ ਮਿਤੀ ਅਤੇ ਜੀਨੋਟਾਈਪ ਨਾਲ ਸੰਬੰਧਿਤ ਦੇਖਿਆ ਗਿਆ। ਜੀ ਜੀ ਈ ਬਾਈਪਲਾਟ ਮਾਡਲ ਨਾਲ ਬਾਈਪਲਾਟ ਗ੍ਰਾਫ ਬਣਾਏ ਗਏ, ਜੋ ਜੀਨੋਟਾਈਪ ਦੀ ਵਿਭਿੰਨਤਾ ਅਤੇ ਜੀ x ਈ ਦੀ ਆਪਸੀ ਪ੍ਰਕਿਰਿਆ ਅਤੇ ਜੀਨੋਟਾਈਪਾਂ ਦੀ ਗਿਣਾਤਮਕ ਅਤੇ ਗੁਣਾਤਮਕ ਗੁਣਾਂ ਨੂੰ ਦਰਸਾਉਂਦਾ ਹੈ। ਗਾਜਰ ਦੇ ਰੂਪੀ, ਜੈਵ ਰਸਾਇਣਕ ਅਤੇ ਬੀਜ ਪੈਦਾ ਕਰਨ ਦੀ ਸਮਰੱਥਾ ਵਰਗੇ ਗੁਣ ਦੂਸਰੀ ਜਗ੍ਹਾ (ਕੇ ਵੀ ਕੇ ਲੰਗੜੋਆ) ਤੇ ਸਭ ਤੋਂ ਵਧੀਆ ਪਾਏ ਗਏ। ਰੂਪੀ ਗੁਣ ਜਿਵੇਂ ਕਿ ਜੜ੍ਹਾਂ ਦੀ ਲੰਬਾਈ, ਭਾਰ, ਚੌੜਾਈ ਅਤੇ ਕੁੱਲ ਉਤਪਾਦਕਤਾ (ਕਿਲੋ/ਪਲਾਟ) ਆਦਿ ਗਾਜਰ ਦੇ ਜੀਨੋਟਾਈਪਾਂ-ਕੈਰਟ ਨੈਨਟਸ, P-35, P-41 ਅਤੇ ਕੈਰਟ ਅਰਲੀ ਨੈਨਟਸ ਜੋ ਕਿ ਨਵੰਬਰ ਦੇ ਪਹਿਲੇ ਹਫਤੇ ਬੀਜੇ ਸਨ, ਦੇ ਵਿੱਚ ਸਭ ਤੋਂ ਵੱਧ ਪਾਇਆ ਗਿਆ। P-35, P-5, ਅਰਕਾ ਸੂਰਜ ਅਤੇ P-16 ਜੀਨੋਟਾਈਪਾਂ ਵਿੱਚ ਕੁੱਲ ਘੁਲਣਸ਼ੀਲ ਠੋਸ, ਕੈਰੋਟੀਨ ਦੀ ਮਾਤਰਾ ਅਤੇ ਮਿਠਾਸ ਦੀ ਮਾਤਰਾ ਕਾਫੀ ਮਾਤਰਾ ਵਿੱਚ ਪਾਈ ਗਈ। ਕੈਰਟ ਨਾਨਟੈਸ, PCO-4 ਅਤੇ PCO-6 ਜੀਨੋਟਾਈਪਾਂ ਵਿੱਚ ਬੀਜਾਂ ਦੀ ਗੁਣਵੱਤਾ ਅਤੇ ਬੀਜ ਪੈਦਾ ਕਰਨ ਦੀ ਸਮਰੱਥਾ ਜਨਵਰੀ ਦੇ ਪਹਿਲੇ ਹਫਤੇ ਬੀਜਣ ਤੇ ਵੱਧ ਦੇਖੀ ਗਈ।

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CHAPTER-I

INTRODUCTION

Carrot (*Daucus carota* L.) is an important vegetable crop world wide economically, nutritionally and as a protective food. It is diploid ($2n=2x=18$) and belongs to Umbelliferae family. Temperate or European carrots are orange coloured and rich in β -carotene, a precursor of vitamin A. The supply of 5.2-6.0 mg β -carotene/day can prevnt cancer as carotenoids may act as antioxidant by quenching singlet oxygn and triplet excited states (Palozza and Krinsky, 1992). In general, carrots are rich source of dietary fibre, antioxidants and minerals. It is used in various forms as raw and cooked. Besides, it has uses in juices, vegetable soups, sauces, pickles, curries and canning etc. Carrot covers 97,000 ha area with 16,48,000 MT production in India and yields about 16.99 MT/ha (Anonymous 2018a). The area under carrot in Punjab is 89,000 ha with an annual production of 1,97,000 MT and average yield of 22.2 MT/ha (Anonymous 2018b).

The origin of carrot is Afghanistan (Banga, 1976). Asian carrots are expected to be originated in Afghanistan and neighbouring regions of Russia, Iran, India, Pakistan and Anatolia. Asian (Purple) carrot along with yellow carrot widespread over the region of Mediterranean and Western Europe, China, India and Japan. The wild carrot was the progenitor of the cultivated carrot (Simon 2000) and before it was domesticated, wild carrot was ubiquitous, as seeds of wild carrots were bring into Europe nearly 5,000 years ago. The process of domestication of wild carrot transformed the small and profoundly divided strong flavoured taproot with annual and biennial flowering habit into a large, smooth and good storage root of biennial or annual crop. It took century to select the swollen type of carrot root for domestic consumption.

Carrot is highly beneficial for mankind as it consists of numerous nutritional and health benefits due to the presence of carotenoids, flavonoids, vitamins and minerals. Different coloured carrots like yellow, white, purple, red and orange contains diverse carotenoid pigments. Red carrots are rich source of lycopene, yellow carrots have high contents of xanthophylls, orange carrots consists of β -carotene, purple carrots have anthocyanin pigment whereas white carrots are devoid of pigments (Rubatzky *et al* 1999). The pigments like carotenoids and phenolics present in carrot roots act as antioxidants which exert a variety of health-related benefits (Ross and Kasum 2002). According to the old saying that carrots are admirable for human eyes; vitamins and carotenoids present in carrot perform as anticarcinogens, immune relishers and proves carrot as a boon for human eyes. Khandare *et al* (2011) observed that black colored carrot contains anthocyanin pigment which possess antioxidant property. Poudyal *et al* (2010) compared the ability of juice and β -carotene content in purple colored carrot so as to overturn the structural fluctuations in rats and

concluded that the anthocyanin content of purple carrot is reliable for the conditions of rats. Carrot contains provitamin A and carotenoids which are highly effective in reducing the post-menopausal breast cancer (Swamy *et al* 2014).

Carrot is a cool season crop and requires deep, well drained and light loam soil. Mainly, there are two types of carrots i.e. Asiatic and European types. Asiatic types commonly include carrots with purple roots as well as yellow coloured roots. European types of carrot were originated from the Asian carrots. Asiatic type of carrots needs warmer temperature whereas European type of carrots requires a cooler climate. Asian carrots are poor in β -carotene content but they are high yielding and produce roots as well as seeds under tropical conditions. European carrots are rich in carotene content, total soluble solids and dry matter content but low yielding and produce seeds only in temperate conditions (Gill and Kataria 1974). Asiatic types of carrot are annuals and require 10°-15° C temperature for root development and 15.5°-21.1°C for colour development. Very high or low temperature is not conducive for proper development of roots. The temperature above 30°C causes undesirable strong flavor and coarseness in the roots. European carrots are more sensitive to temperature and requires 4.8°-10°C temperature during the development of roots and contains orange coloured carrots viz. Nantes, Danver and Imperator.

Carrot is protandrous in nature having compound inflorescence called as umbel. An umbel consists of 50 or more umbellets. Firstly, primary umbels mature which shows the highest viability and two to three times more seeds than succeeding umbels. Due to uneven maturation, seed produced in umbels vary in physiological quality. For carrot seed production, staggered pickings of the umbels are adopted. The Asiatic types produce seed in Punjab, Haryana, Uttar Pradesh and parts of Rajasthan & Gujarat whereas the seed of European types is formed in temperate regions like Sproon valley, Kullu valley, Kalpa valley of Himachal Pradesh, Kashmir valley of Jammu & Kashmir and selected locations of North East region specially Sikkim and Arunachal Pradesh. Although, root crops are well adapted to cool season but its seed production is being done in plains and hills during winter or after over wintering. The Asiatic/tropical varieties produce their seeds freely in the plains without chilling requirement and seeds germinate well at 7.2-23.9°C whereas temperature below 15°C may results in formation of seed stalks which is suitable for seed production. The temperate/European types need chilling/vernalization requirement of 4-5°C temperature for 40-60 days duration for bolting depending upon the range of temperature. Therefore, their seed production is organized in hilly areas. The seed formation of European carrots takes place at 12.2°-21°C. The mild summer and low rainfall of hills especially during flowering and seed setting stages are beneficial. High temperature at flowering in carrot also causes desiccation of tertiary umbels due to reduced availability of pollen supply for secondary umbels which ultimately reduces the seed setting and lowers seed yield.

Genetic variability is a measure of the ability of individual genotype in a population to differ from one another. The important factor in evaluation is variability as it affects the response of individual genotype to environment. The best genotypes can be selected by an important factor i.e. genetic variability for growing at optimum period of time because most of plant characters are polygenic in nature and are influenced by environment. It is necessary to work out whether the observed variability is heritable or due to environment. For adaptability and phenotypic stability, GxE interaction partitioned in studies (Cucolotto *et al* 2007). GxE is the analysis which is applicable to any number of varieties in any number of environments. This analysis results into informative conclusions that can be used to predict across generations as well as across environments. When more than one environment is considered, it becomes complicated to investigate a quantitative character genetically because with the change in environment, there is a change in gene expression. The important source of phenotypic variation is said to be GxE interactions. The success of any breeding programme depends on the nature and magnitude of genetic variability present in the species. GxE interactions are to be performed to check whether temperate cultivars of carrot grow well under our sub-tropical conditions or not.

The diverse agroclimatic conditions prevails in different zones of Punjab and very less significant research work has been done on European genotypes of carrot in Punjab. So, germplasm of European carrots collected from different sources has been evaluated in different regions of Punjab. Therefore, Department of Vegetable Science, PAU, Ludhiana evaluated the germplasm of European carrots for morphological and biochemical traits and their seed production potential. Characterization and evaluation of germplasm at phenotypic level would help to ascertain genetic relationship and differences among the study material. Therefore, the present study has been formulated to widen the crop improvement programme with the following objectives:

- To identify the most promising genotypes of carrot in each environment.
- To identify the best season for seed production of different genotypes of carrot.

CHAPTER-II

REVIEW OF LITERATURE

Genetic variability present in the population is the key for the success of a breeding program. Johenssen (1904) gave the concept of genotype and phenotype and accomplished that variation within a pure line is due to non-heritable sources. Understanding the interactions among different germplasm and environment is an important aspect for development of crop plants. It can be practiced for selection of promising genotypes in different agro-ecological conditions.

Identification of germplasm lines within a species is relatively difficult due to large data collection, unknown genetic control of the traits and many of traits have a polygenic effect and are influenced by environmental conditions. Biochemical characterization is based upon the enzymatic activities and morphological study is also very crucial for germplasm selection. Both these parameters are highly important for selecting the most promising genotypes in diverse climatic conditions.

Root vegetable carrot has the power of flexibility under different agroclimatic conditions. Major breeding objectives for carrot include high root yield, self-cored, thick and long roots, root color, early maturity, good quality characteristics (carotenoids and TSS). The present study undertakes to evaluate carrot germplasm of diverse geographic origin.

The critical review of literature related to the evaluation and seed production potential of diverse European genotypes has been studied under two sub headings:

2.1 Morphological and biochemical variability

2.2 Seed production potential

2.1 Morphological and biochemical variability

Genotype identification focused on quantitative and qualitative features like plant height, root length and weight, total and marketable root yield, root and core color, root shape, TSS, carotene content and several other methods of genotype consideration. The morphological variability is measured by the interaction of genotype with environmental factors (G X E). For sustainable agriculture, genetic variability conservation of crop plants has great importance.

Singh *et al* (2017) studied the nature of genetic diversity in germplasm of carrot and classified forty European carrot genotypes by using the multivariate analysis. All the genotypes classified for four principal components. Component PC-I, with high positive loading for root weight, root diameter, root weight and yield (q/ ha), PC-II had the high positive loading for root: top ratio, PC-III for top length and PC-IV for flesh thickness. Clusters II and IV had the highest inter-cluster distance and study concluded that the most suitable parent for crop improvement is the one which had high inter-cluster distance.

Teli *et al* (2017) reported about the magnitude of the PCV was higher than GCV for all the characters. Carotene content, root shoot ratio and root yield per hectare showed the highest values of GCV and these are the most important traits for carrot crop improvement. Mahmood *et al* (2017) conducted analysis of profitability of carrot production in selected districts and the results indicated that growing carrot is successful agro enterprise in Punjab and Pakistan during winter season. Sanghera *et al* (2017) studied GxE interactions on five genotypes of sugarbeet in nine environments i.e. three sowing dates and three locations. They concluded that there are some genotypes that are stable in different environment conditions and are being used in crosses with the cultivars which have agronomically desirable traits.

Sivathanu *et al* (2015) studied ten genotypes of radish and evaluated fourteen characters under Rabi, summer and Kharif seasons to study stability parameters and concluded that most of the characters are inclined by season apart from leaf width, root length, root/leaf ratio, dry weight of leaves per plant and plant fresh weight. Guler *et al* (2015) projected total number of VOCs/sample in 11 different carrot cultivars ranged from 17 to 31. Primarily VOCs identified in raw carrots with the exception of “Yellow Stone” were terpenes. They also observed that monoterpenes are higher than those of sesquiterpenes and purple and yellow Stone, correspondingly consist of α -terpinolene, monoterpenes and consequently, more than 60% of total VOCs recognized in carrots.

Latha (2015) researched on different carrot genotypes with respect to different sowing dates and concluded that there are some combinations of genotypes and environments at different sowing times which results in better growth and high yield of carrot cultivars. Priya and Santhi (2015) estimated the high values of genotypic coefficient of variation (GCV) for root splitting percentage, total chlorophyll, root carotene content and root forking percentage. The character association studies indicated the strong positive association of root yield with root carotene content, root weight, root length, root diameter, inner core diameter, root forking percentage, root splitting percentage and leaf carotene content. High heritability coupled with high genetic advance as per cent of mean was noticed with four yield components *viz.* leaf carotene content, root carotene content, total chlorophyll and root weight. Sagar and Kalia (2015) checked different carrot genotypes and noticed that the high degree of beta-carotene is crucial to maintain better flavor. The genotype NS-16 followed by SH and Pusa Yamdagini recorded as the best genotypes for the developing dehydrated carrot pieces.

Carrot roots produce tocochromanol complexes. Range variation and amount of this complex in a different carrot genotypes throughout postharvest storage and reproductive stages were determined. The amount of α -tocopherol presented in carrot roots was comparable to other vegetables like lettuce and red pepper (Luby *et al* 2014). Mehrab *et al* (2014) considered the nine Iranian carrot genotypes and evaluated on the basis of phenotypic

traits which consisted of twelve qualitative traits and eighteen quantitative traits. The results of quantitative traits revealed that Esfehan and Kerman genotypes had the highest yield than the other genotypes. In qualitative traits, root color in Shoshtar was purple and Esfehan had red colored root while other accessions were yellow colored. Total cumulative variance for five key components of morphological characters was 88.17%. Morphological characterization included cluster investigation and placed yellow carrot genotypes into three groups.

Kasiri *et al* (2013) observed morphological characters of Iranian yellow colored carrot genotypes. Cluster analysis differentiated the genotypes into three main groups, two Asian and one European. The Iranian yellow carrots which belongs to Asian group contains characters like yellow roots and intermediate dissection and parsley leaf type. Additionally, positive and negative correlations between root and leaf were simply correlated. Yildiz *et al* 2013 reported five structural genes expressed separately and in declining order, when it was compared with solid-purple and orange carrots with transcript addition coinciding with anthocyanin content accumulation.

Fleming and McCormack (2012) performed an experiment to check the change in leaf size of various radish cultivars in different environmental conditions. They took two samples, raised them in two incubators and compared the average leaf sizes of radish cultivars grown in the warmer versus cooler temperatures and concluded that growth rates and leaf sizes increases for the plants raised in the warmer incubators. Hence, Radish showed its response in various terms to different environmental conditions. Gupta *et al* (2012) studied 100 genotypes of European types of carrot and reported that the net marketable root weight/plot expressed positive root girth, gross weight/five plants and net root weight/five plants.

Kumar *et al* (2011) used the genetic material which consisted of 30 European carrot genotypes and selected them on the basis of agronomic and other traits like mean root yield per plot, β -carotene content and TSS. Their study resulted in a wide range of genetic variability which exists in all characters except root forking. The secondary root production showed the highest range for genetic advance for all the characters.

Amin *et al* (2010a) investigated the genetic divergence between pairs of traits and their contribution to root yield of different genotypes. All the genotypes were divided into 14 clusters and maximum inter cluster distance was recorded between cluster VI and I which indicated that the wide diversity exist between these two clusters. Parameters like weight of marketable roots per plot, root weight, shoot weight per plant and per cent marketable roots were used for selection of genotypes and proved to be more efficient. Gajewski *et al* (2010) estimated the carotenoid compounds in five cultivars of carrot. Total carotenoids and β -carotene contents in the carrot roots were noticed after the harvest by means of the standard spectrophotometric method. The experiment resulted in carotenoid accumulation in the roots

which was significantly affected by carrot genotype. 'HY7842' carrot showed the highest accumulation of total carotenoids and β -carotene content.

In carrot, eighty four cultivars from twenty one countries were collected, these thirty eight proved to be reliable local varieties, which represents 45.2% of total and five were homologated carrot varieties. The biochemical analysis mean values indicated dry matter content: 12.7% in local varieties and 9.4% in homologated varieties; total carbohydrate: 6.3% in local varieties and 3.7% in homologated varieties; total carotenoid: 10% in local varieties, with minimum of 1.9% and maximum of 23.2 mg/100 g. The average degree attack by *E. carotovora* was 7.2% in local varieties and 8.3% in homologated varieties (Maxim *et al* 2009). Diversity analysis in carrot genotypes based on morphological and biochemical traits using cluster approach concluded that the content of carotenoids is significant in the assessment of diversity in carrot because the high carotenoid content is an indicator of high nutritional values and higher the content of carotenoids, lesser will be the undesirable compounds. Yadav *et al* (2009) recorded great variability for different characters in carrot genotypes and recorded the highest root weight (81.00 g), root length (17.67 cm) and root yield (216.6 q/ha) in Desi Red. Phenotypic and genotypic coefficient of variation varied from 3.71 to 20.88 % and 2.46 to 15.75%, respectively. The PCV and GCV varied from 3.7 to 15.8 % and 2.4 to 15.8 %, respectively. The highest heritability was recorded for TSS (83.00 %) and lowest for root length (26.2%). Root to shoot ratio, root weight and root yield showed strong positive correlation. Root weight showed maximum direct effect on yield.

Carrot roots (*Daucus carota* L. cv. Nevis F₁) were verified for the yield of carotene content at temperatures 20°C, 40°C and 60°C and the samples have been inspected after cold storage at 5°C and freezing at -18°C treatments. In the technology of the carotenoid concentrate production from carrots, it was found that the solubility and yield of this antioxidant depend on the temperature, time of extraction as well as the treatment of the sample. It was exposed that the best extraction efficiency was accomplished with the samples treated with freezing and using the extraction at 60°C for 2-4 hours. Higher temperature caused an increase in the carotenoid concentrations. The variety Nevis F₁ and the extraction at 60°C were used for the model production of carotenoid concentrate (Fikselová *et al* 2008).

Twenty seven genotypes of European carrot including 14 open pollinated varieties and rest of 13 hybrids along with two check varieties were evaluated for different growth and yield parameters. All the genotypes significantly varied for qualitative and quantitative traits (Gupta *et al* 2006). Karkleliene (2006) evaluated carrot cultivars and hybrids in Lithuania for quantitative and qualitative traits and observed that the roots of Bangor hybrid were superior with respect to length (23.9 cm), root diameter (4.3 cm) and root weight (166.7 g) and also had excellent marketable appearance than other cultivars and hybrids.

Bhatia *et al* (2002) studied fourteen characters in 30 carrot genotypes and observed

that total root yield was significantly and positively correlated with root weight (0.923), number of leaves per plant (0.593), shoot weight per plant (0.488) and weight of unmarketable roots per plot (0.738). Root weight in turn had positive and significant correlations with number of leaves/plant, leaf weight/plant, unmarketable roots/plot and weight of marketable roots/plot. Rosenfeld *et al* (2002) studied cultivation of carrot at different temperatures viz. 9°C, 12°C, 15°C, 18°C, 21°C and resulted that with an increase in growth temperature, terpene flavor decreases which is responsible for bitterness in carrots. Pariari *et al* (1992) studied nine quantitative and two qualitative traits in three cultivars of carrot and observed that root length, root weight and top weight were significantly and positively correlated with yield. However, root length and root weight showed significant and negative correlations with total sugar content which is the main indicator of quality in carrot.

Alasalvar *et al* (2001) studied four different colored carrots like orange, purple with the orange core, yellow and white for phenolic content, antioxidants and for volatile substances. They identified total 35 volatiles in all carrots, with 27 have positive effect. White carrot contained the highest concentration of volatiles substances followed by orange, purple, and yellow colored carrots. In total 11, 16, 10, and 9 phenolic compounds were determined for the first time in orange, purple, yellow and white carrots, respectively. Purple carrots contained 2.2 and 2.3 times more alpha and beta-carotenes than orange carrots, respectively. Purple carrots may be used in place of other carrot varieties to take advantage of its nutraceutical components.

Kahangi *et al* (1988) investigated that the carrot cultivars flowered and produced seed in artificial vernalization at 2°C, 8°C at Juja, Kenya and concluded that at 8°C Royal Chantenay produced less seed than Nantes and Danvers Half Long whereas at temperature 2°C for vernalization, Nantes produced higher seed as compared to Danvers and Royal Chantenay.

Gray *et al* (1987) studied that carrot cultivars Chantenay Red-cored and Royal Chantenay raised at day/night temperature i.e. 20/10°C, 25/15°C and 30/20 resulted in higher seed setting at maximum temperature.

Simon (1981) revealed that there is vast information available on GxE interactions on the flavor of carrot in history. He determined that there is a considerable change in the flavor of carrot due to change in environment. Bhagchandani and Choudhury (1980) studied 6 inbred lines and their 30 F₁ hybrids. They reported positive and highly significant correlation coefficient of root weight with leaf length, top weight, root length and root diameter. Gill *et al* (1987) developed a new variety 'Pusa Yamdagini' and compared it with Nantes Half long. When evaluated at ten different sites in the country, Pusa Yamdagini recorded 16.43-143.55% more yield/ha, 30.62-95.21% higher root weight and 8.87-12.29% more carotene content than Nantes Half long.

Dowker *et al* (1978) conducted two experiments in field and observed root

length/diameter (LD) ratio of carrot along with genotype × environmental interactions and suggested that LD ratio would be linear if it had been tested in more than one environment. Michalikh *et al* (1977) noticed that carotene content in the carrot roots (Nantes) increased with time, reaching the highest level at 116 days from sowing and then declined. Carotene content of the roots was season dependent especially in the period preceeding harvest and wet weather resulted in low carotene content. Large roots contain more carotene than small roots. The top part of the root showed the highest carotene content followed by the middle part and the least content present at the distal end of the roots. The outer part of the root (Phloem) contained more carotene than the inner part (xylem) irrespective to size of the roots.

Dowker *et al* (1975) considered characteristics of five colours in seventeen carrot trials in which four varieties of the Chantenay type and four of the Autumn King type were grown at two densities at several sites for three years and results shown that the most efficient selection for a colour character in one season and with four test plots per family, would be achieved when such plots were grown at four separate sites.

Quagliotti (1965) reported that morphogenesis of the flowering stalk of carrot (*Daucus carota* L.) is temperature effective which was investigated along with seed production and other breeding methods of carrot. He concluded that when temperature is 26°C flowering in carrot plants occur earlier 26°C than at 20°C and similarly plants flowered earlier at temperature is 20°C than at 14° C.

2.2 Seed Production Potential

Seed is the most basic and cheapest unit of crop production and efforts of all other inputs such as fertilizers and pesticides for increasing crop yield can be realized only when a good quality seed is sown. Carrot bears seed in umbels as the inflorescence of carrot is compound umbel. A primary umbel which have 1000 flowers at maturity and secondary, tertiary, quaternary umbels per fewer flowers. The floral development of carrot is centripetal i.e. the flowers dehisce first are on the outer edges of the outer umbellets. Carrot is protandrous. The commercial growers make a single harvest when the whole seed crop is judged to be ripe, the harvested crop therefore comprising of seeds at different stages of development and this could be a source of variation in subsequent seedling emergence and growth. The start of flowering, seed development and seed ripening in the carrot crop does not occur synchronously on each umbel order reported by Hawthorn *et al* (1962).

Tabor *et al* (2016) initiated to check the ability of producing seeds of some Asiatic carrot cultivars under tropical conditions of Ethiopia and came to a result that Long Beauty and Deep Red produce good seeds but Nantes have higher potential of producing seeds. Likewise AUA-108 and DZARC-5 (cultivars of purple carrot) have higher seed production potential and are said to be good carrot.

Ghonaime *et al* (2011) conducted an experiment of using gibberellic acid to determine

the seed setting potential and seed quality of carrot cultivars and concluded that by this treatment potentiality of producing carrot seed by cultivars like Chantenay Red Cored increases with an increase in seed quality and its size.

Mengistu *et al* (2010) conducted an experiment to investigate the effect of sowing date and planting density on yield and quality of carrot seeds. They concluded that the seed yield is in correlation with the number of branches per plant, number of umbellets per umbel, seed weight per umbel and umbel diameter. Panayotov (2010) observed from the study that germination was the highest for the seeds from primary umbels, followed by the ones from secondary umbels and lowest for those from the tertiary umbels. The difference between the highest and the lowest value was 6.30%. The results of his study suggested that it is better to harvest the carrot seeds depending on their position on the plant and divide them into separate lots with different qualities.

Corbineau *et al* (2008) studied about the various sources of germination heterogeneity of carrot (*Daucus carota* L.) seeds and investigated germination conditions, size of seeds, position of the umbels on the mother plants and pollination conditions of male-sterile plants in hybrid seed production. Seeds were tested for germination over a large range of temperatures (5-35°C). However, low temperatures (5-10°C) and temperatures above 30°C reduced germination. Seeds were also sensitive to oxygen deprivation but their sensitivity to hypoxia depended on the cultivar. The germination responses of seeds to temperature and oxygen depended on their size, particularly at sub- and supra-optimal temperatures. The largest seeds (1.8-2.1 mm) of commercial lots usually germinated better at 5°C and were more sensitive to oxygen deprivation than the smallest ones. The study performed with open pollinated plants showed that seeds produced by umbels of first and second orders germinated faster and at higher percentages than those collected on third-order umbels.

Pereira *et al* (2008) studied about different factors that influence the establishment of carrot crop like high temperature (35 - 40°C) delays the germination of carrot seed in field. Results of the study prove that carrot seeds germinated well at 20°C than 35°C. Also, seeds from primary and secondary umbels order have less aged seed lots with high vigor and germination.

Amjad *et al* (2004) reported that seed vigor and conductivity of seed leachates are the main characteristic of seed quality and are used to estimate the quality of seed lot.

Elballa *et al* (1996) conducted a study to check the effect of temperature on seedstalk development, seed yield and quality in carrot was investigated in growth chambers at constant day/night temperatures of 33/28, 28/23, 25/20, 23/18, 20/15, and 17/12 °C. Days to flowering, seedstalk height, number of umbels, and seed yield decreased linearly with increasing temperature from 17/12 to 33/28 °C. Continuous high temperature (33/28 °C) had a detrimental effect on germination as measured by a standard germination test and an

accelerated aging test. Optimum germination of the progeny occurred at 20/15 °C however, germination rate was faster when seeds matured at 23/18 °C. The study resulted that high (33/28 °C) day/night temperatures during pollination and early stages of seed development can reduce carrot seed yield and seed quality.

Corbineau *et al* (1994) explained that the germination of carrot seeds is very sensitive to low temperatures and to oxygen deprivation.

Viggiano (1990) observed that the seed quality of carrot is also affected by the period of harvest. During seed production of carrot, flowering on plants is non-uniform and continues with umbels of each order. Hence, time of harvesting and its composition in terms of umbels are of fundamental importance for maintaining carrot seed quality.

Gray (1984) reported that the carrot seeds from protected conditions have high germination percentage as compared to the seed produced in natural conditions. Gray *et al* (1984) showed a relationship between the seed weight and endosperm volume of carrot and concluded that this relationship is similar for primary and secondary umbels but it was affected by the season of seed production.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the materials used and methodology followed in conducting the experiment. The location of the experiment, climate, materials used and methods followed in different operations during conducting the experiment as well as in data collection are described here under the following sub-heads:

3.1 Experimental site

The present investigation entitled "Evaluation and seed production potential of European genotypes of carrot (*Daucus carota* L.) under different agroclimatic conditions of Punjab." was conducted at Research Farm (Director Seeds), Punjab Agricultural University, Ludhiana (30° 54" North latitude and 75° 50" East longitude at an altitude of 247 meters above sea level) and KVK Langroya, Shaheed Bhagat Singh Nagar (31° 07" North latitude and 76° 07" East longitude at an altitude of 283 meters above sea level) during 2018-19.

3.2 Climate

Ludhiana- Ludhiana falls under central plain zone (Agro Climatic – I zone) of Punjab having semi-arid climate. The average annual rainfall of this zone is 726 mm. The climate of Ludhiana is humid subtropical. In summer months, climate is hot and dry while climatic conditions during the period of July to September show slightly low temperature and high humidity.

Langroya – KVK Langroya falls under undulating plain region (Agro Climatic – III zone) of Punjab. The average rainfall of this zone is 1000 mm. The climate of Langroya is sub humid. Mostly, the climate is humid but during the months of September, October and November, it is inter- humid to wet.

3.3 Meteorological conditions during crop season

Table 3.3.1 Weekly meteorological data recorded at meteorological observatory during 2018-19 in Ludhiana

Standard meteorological week	Temperature (°C)		Mean
	Maximum	Minimum	
36	33.4	26.1	29.75
37	33.4	25.2	29.3
38	31.1	22.3	26.7
39	29.9	21.3	25.6
40	32.5	20.5	26.5
41	30.8	18.6	24.7
42	31.7	16	23.85

43	26.2	14.2	20.2
44	29.6	16.2	22.9
45	27.1	11	19.05
46	26.4	11.5	18.95
47	27.1	10.8	18.95
48	25.8	10.1	17.95
49	22.7	7.7	15.2
50	20.3	7.4	13.85
51	20.3	3.6	11.95
52	18.4	2.8	10.6
1	18.2	6.7	12.45
2	19.8	6.0	12.9
3	19.3	6.2	12.75
4	17.2	5.9	11.55
5	19.1	6.3	12.7
6	19.4	8.4	13.9
7	19.9	10.6	15.25
8	21.1	10.3	15.7
9	20.0	9.6	14.8
10	22.7	10.0	16.35
11	24.6	10.7	17.65
12	26.9	12.9	19.9
13	31.1	14.7	22.9
14	34.3	18.3	26.3
15	35.0	19.9	27.45
16	31.3	18.1	24.7
17	39.3	21.9	30.6
18	37.7	21.3	29.5
19	39.4	21.9	30.65
20	34.5	22.1	28.3
21	38.4	22.1	30.25

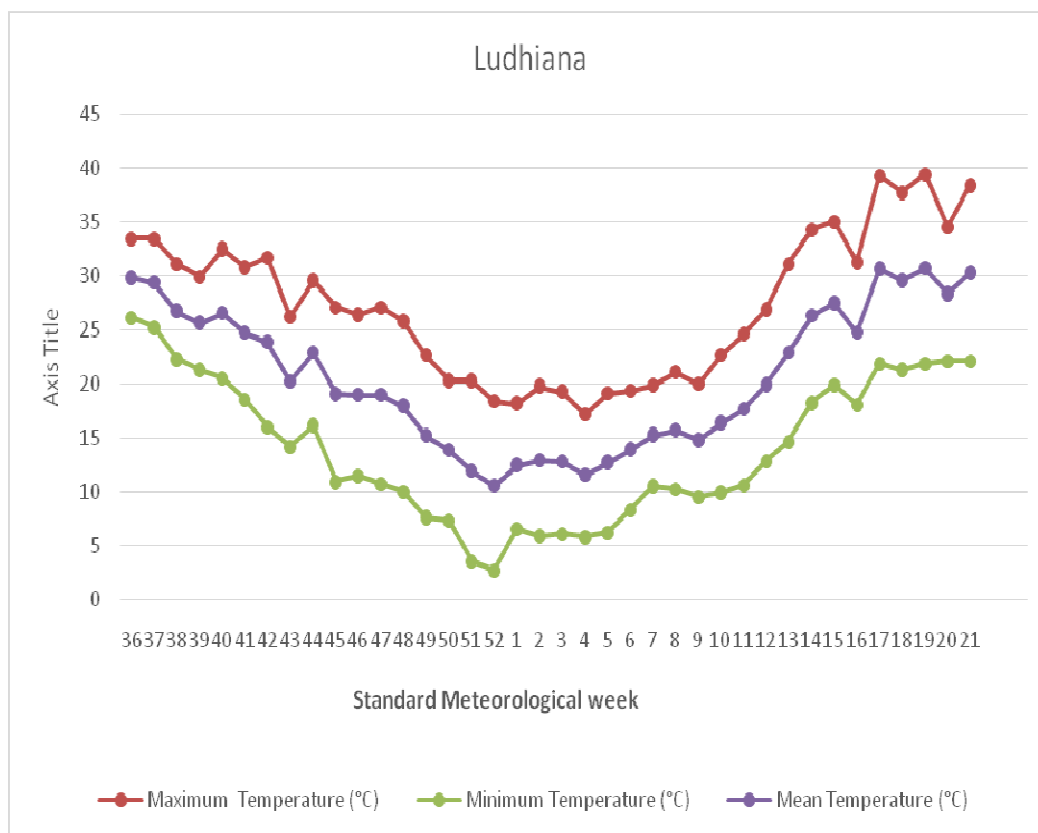


Fig 3.1 Graphical representation of weekly mean maximum, minimum temperature, rainfall during crop season at Ludhiana (September 2018-May 2019).

Table 3.3.2 Weekly meteorological data recorded at meteorological observatory during 2018-19 at KVK, Langroya

Standard meteorological week	Temperature (°C)		Mean
	Maximum	Minimum	
36	33.3	22.6	27.95
37	33.3	21.9	27.6
38	34.4	21.6	28
39	32.0	21.8	26.9
40	33.9	21.3	27.6
41	33.9	19.5	26.7
42	33.6	17.4	25.5
43	32.1	14.7	23.4
44	28.5	13.8	21.15
45	27.1	13.0	20.05

46	25.7	11.9	18.8
47	23.5	9.0	16.25
48	24.3	7.8	16.05
49	23.6	6.9	15.25
50	20.4	9.5	14.95
51	19.8	6.4	13.1
52	22.3	6.9	14.6
1	15.7	4.8	10.25
2	19.6	4.5	12.05
3	22.5	5.5	14
4	17.8	6.1	11.95
5	20.4	5.9	13.15
6	22.0	5.6	13.8
7	21.7	7.8	14.75
8	25.2	10.6	17.9
9	26.65	14.01	12.03
10	26.64	11.71	19.2
11	29.74	14.54	22.1
12	28.77	13.77	21.3
13	31.88	15.82	23.9
14	33.071	18.64	25.9
15	31.6	17.54	24.6
16	35.64	19.9	27.8
17	36.55	18.94	27.8
18	36.67	20.7	28.7
19	38.6	21.0	29.8
20	35.2	20.8	28.0
21	37.0	21.4	29.2

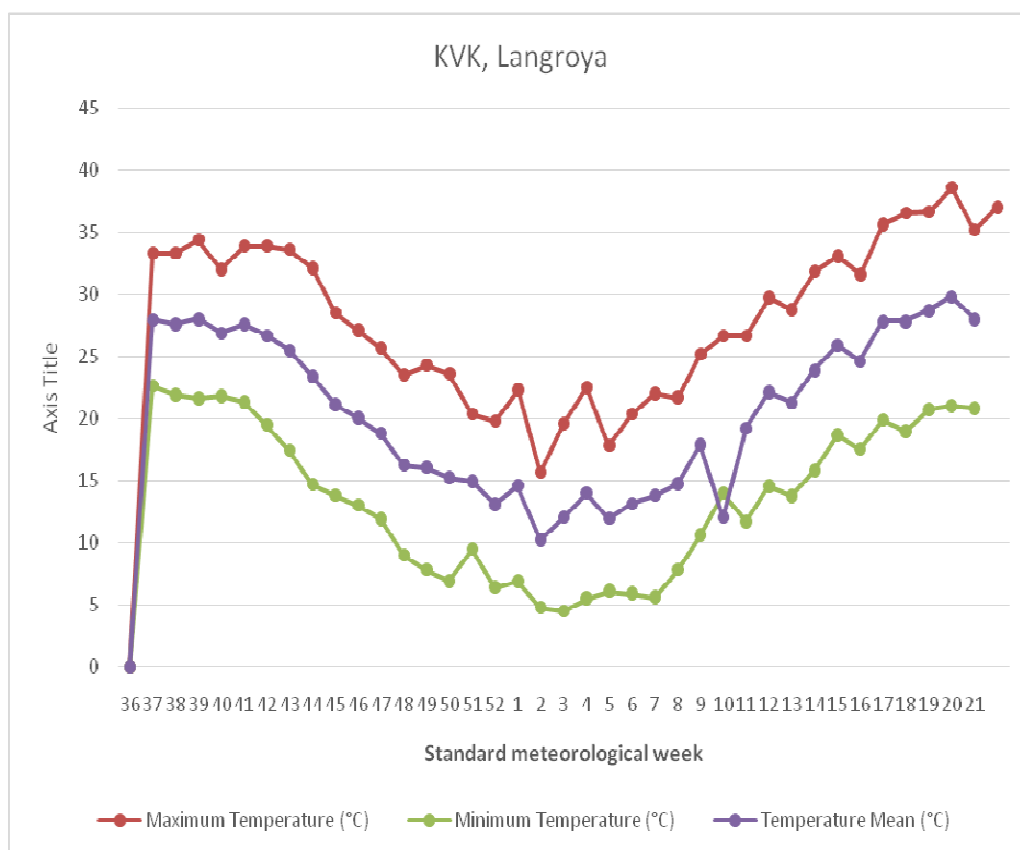


Fig 3.2 Graphical representation of weekly mean maximum, minimum temperature, rainfall during crop season at KVK Langroya (September 2018-May 2019).

3.4 Experimental details

3.4.1 Experiment 1: Evaluation of diverse genotypes of carrot under different Agroclimatic conditions of Punjab

3.4.1.1 Treatments

The experiment comprised of two parameters i.e. Date of sowing and genotypes

A) Date of sowing

Sowing dates	Symbols used
First week of September	E ₁
Last week of September	E ₂
Second week of October	E ₃
First week of November	E ₄

B) Genotypes

Seventeen genotypes were used for characterization:

Genotypes	Source	Symbols Used
P-3	PAU, Ludhiana	G1
P-4	PAU, Ludhiana	G2
P-5	PAU, Ludhiana	G3
P-16	PAU, Ludhiana	G4
P-17	PAU, Ludhiana	G5
P-18	PAU, Ludhiana	G6
P-23	PAU, Ludhiana	G7
P-28	PAU, Ludhiana	G8
P-29	PAU, Ludhiana	G9
P-35	PAU, Ludhiana	G10
P-41	PAU, Ludhiana	G11
PCO-4	PAU, Ludhiana	G12
PCO-6	PAU, Ludhiana	G13
Carrot Nantes	IARI, New Delhi	G14
Carrot Early Nantes	IARI, New Delhi	G15
Pusa Meghali	IARI, New Delhi	G16
Arka Suraj	IIHR, Bangalore	G17

C) Layout and Design

The experiment was conducted with four sowing dates and 17 genotypes. The experiment was laid out in split plot design with three replications. Each genotype was planted on 67.5 cm raised beds (37.5 cm bed and 30 cm furrow) in 4 rows with spacing of 10 cm between rows and 8 cm between plants.

3.4.1.2 Observations recorded

Morphological characterization

1. Plant height (cm)

Ten plants were randomly taken from each treatment over replications and height of the plant was measured with the help of meter scale at ground level to top of the plant at marketable root harvest stage and the average was calculated.

2. Shoot weight (g)

Shoot weight was measured in grams with electrical balance. Shoot weight of ten plants was recorded soon after uprooting and the average weight per plant was calculated.

3. Shoot length (cm)

Shoot length was measured from the top of the carrot to the first open leaf. Ten randomly selected plants were used to record the shoot length.

4. Root length (cm)

Root length was measured from the tip to the bottom of the randomly taken roots of

each treatment in each replication at marketable root harvest stage. The mean of the ten plants were calculated for statistical analysis.

5. Root weight (g)

The leaves and the tip of the roots used for root length were removed before measurement of length. The roots were washed thoroughly to remove the soil and other particles sticking to root. Root weight of each of the ten randomly taken roots was recorded and the average was calculated.

6. Root girth (cm)

Root girth was measured from one cm below the top of the root with the help of Vernier-Caliper of randomly taken roots of each treatment and replication. Average root girth was measured at marketable root harvest stage.

7. Core girth (cm)

The core girth of randomly taken roots from each treatment and replication was recorded with the help of Vernier-Caliper at marketable root harvest stage. The average of ten roots was calculated from each treatment and the mean was recorded for statistical analysis.

8. Flesh thickness (cm)

Flesh thickness (Root girth - core girth) of the ten randomly taken roots from each treatment and replication was measured with the help of Vernier-Caliper at marketable root harvest stage. The mean was recorded for statistical analysis.

9. Root Shoot ratio

Root shoot ratio of each genotype was measured by comparing the weight of root and shoot separately at final harvest stage.

10. Root colour

Root color was observed visually from the outer color of the roots at marketable root harvest stage and recorded as creamy white, yellow, orange, red, purple and black using color chart Royal Horticultural Society, United Kingdom.

11. Core colour

The roots used for observing root color were cut transversely and core color was observed visually from the core and matched with color chart Royal Horticultural Society, United Kingdom.

12. Total root yield (kg/plot)

Roots at the marketable stage were taken randomly from each plot in different replications and total yield of roots/plot (1.35 m²) and q/acre was recorded.

13. Marketable root yield (kg/plot)

Roots at the marketable stage were randomly taken and the unmarketable roots (forked, intermingled and deformed) were sorted out from the total roots and the marketable root yield was recorded per plot as well as per acre.

14. Days to 1st root harvest

A total number of days were counted from sowing to first root harvest from ten randomly taken plants in each replication.

15. Root forking (%)

It has been recorded at marketable root harvest stage.

Low: 0-20% Medium: 21-40% High: >40%

16. Root Shape

Root shape has been recorded as conical, cylindrical and tapering at marketable root harvest stage from each genotype in each replication.

Biochemical characterization

Data were recorded for following biochemical characters for European carrot genotypes. Biochemical observations were obtained from freshly harvested roots at marketable maturity.

1. Dry matter content (%)

Ten roots from the composite sample were taken randomly, washed, topped and peeled, then these were cut into 3 mm thin pieces. Fifty gram sample from each genotype in each replication was taken and dried to constant weight in an oven at $60 \pm 2^\circ \text{C}$. The dry matter content was estimated by following formula:

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

2. Total soluble solids (°Brix)

An Erma Hand Refractometer was used for direct determination of T.S.S (°Brix) from fresh juice extracted from roots.

3. Total sugar content estimation (Dubois *et al* 1956)

Principle

Sugar form furfurals and hydroxyl-methyl furfurals in the presence of Conc. H_2SO_4 , which react with phenol to give colored compounds. All sugars give this test as oligo and polysaccharides will get hydrolyzed with Conc. H_2SO_4 and also form furfurals.

A) Extraction

a) Reagents

- 1) Ethanol (80%)
- 2) Lead acetate (saturated)
- 3) Sodium oxalate

b) Procedure

Weighed 500 mg dried samples and refluxed with 80% ethanol in a conical flask fitted with a water condenser and refluxed for two hours. Then the supernatant was collected and again refluxed the content with 70% ethanol and pooled the supernatants. Ethanol from

pooled extract was removed at 50°C in a flask evaporator vacuum. Then 1.0 ml of saturated lead acetate was added. This was kept overnight till all the proteins in the extract get precipitated. To this pinch of sodium oxalate was added to remove the lead ions from the extract. It was again kept overnight. Thereafter, the extract was filtered through Whatman no. 1 filter paper. The clear extract thus obtained was made up to 100ml with distilled water for total sugar content estimation.

B) Estimation

a) Reagents

- 1) 5% phenol (w/v) redistilled
- 2) Conc. Sulphuric acid (H₂SO₄)

b) Procedure

To 0.2 ml extract of sugar, 0.8 ml of distilled water and 1.0 ml of 5% phenol was added followed by addition of 5.0 ml concentrated H₂SO₄. The H₂SO₄ was poured directly into the center of the test tube to ensure proper mixing. After 10 min, tubes were cooled to room temperature under running water. After 20 min the absorbance was read at 490 nm against reagent blank. The total sugars content concentration was calculated from a standard curve arranged by using glucose in the range of 10-100 µg/ml.

4. Juice yield per kg roots (ml)

Juice was extracted from one kg roots using Food Processor (Maharaja Whiteline, 600W) and juice was measured using a graduated cylinder.

5. Carotene content (mg/100g)

It was determined by the method suggested by A O A C (1970). Five grams of fresh carrot roots were taken and grinded with 3% acetone in petroleum ether with a pinch of Na₂SO₄. The residue was filtered 2-3 times until the extract become colorless. The contents were poured into a separatory funnel and acetone was washed with distilled water. The petroleum ether layer was separated out. The final volume was made 50 ml with petroleum ether and the optical density reading was taken at 452 nm in a spectrometer (Systronics, 0.08) along with the petroleum ether as blank. The beta-carotene content was calculated from a calibration curve prepared in the same manner using pure beta-carotene content.

$$\text{Carotene content (mg/100g)} = \frac{3.857 \times \text{O.D} \times \text{Vol.}}{\text{Weight of sample (g)}} \times 100$$

3.4.2 Experiment 2: Seed Production Potential of European types of carrot

3.4.2.1 Treatments

Two parameters were included in the experiment i.e. date of transplanting and genotypes

A) Date of transplanting

	Mother root production	Transplanting of stecklings
1.	I st week of September	I st week of December
2.	Last week of September	I st week of January
3.	I st week of October	I st week of February

B) Genotypes

Fifteen genotypes were comprised for seed production potential:

Genotypes	Source	Symbols used
P-3	PAU, Ludhiana	G1
P-4	PAU, Ludhiana	G2
P-5	PAU, Ludhiana	G3
P-16	PAU, Ludhiana	G4
P-18	PAU, Ludhiana	G5
P-23	PAU, Ludhiana	G6
P-28	PAU, Ludhiana	G7
P-29	PAU, Ludhiana	G8
P-41	PAU, Ludhiana	G9
PCO-4	PAU, Ludhiana	G10
PCO-6	PAU, Ludhiana	G11
Carrot Nantes	IARI, New Delhi	G12
Carrot Early Nantes	IARI, New Delhi	G13
Pusa Meghali	IARI, New Delhi	G14
Arka Suraj	IIHR, Bangalore	G15

C) Layout and Design

The experiment was conducted with three dates of stecklings transplantation having 15 genotypes. The experiment was laid out in split plot design with three replications. Each genotype was transplanted at 45×30 cm spacing.

3.4.2.2 Observations recorded

1. Number of branches

Numbers of branches from ten randomly taken seed plants were counted at harvesting stage. All the fully grown branches along with the small tertiary branches were taken into consideration.

2. Number of primary umbels

Number of primary umbels from ten randomly taken plants were counted.

3. Number of secondary umbels

Numbers of Secondary umbels were counted from ten randomly taken seed plants at

harvesting stage. All secondary umbels present at secondary branches were taken into consideration.

4. Number of tertiary umbels

Numbers of tertiary umbels were counted from ten randomly taken seed plants at harvesting stage. All tertiary umbels present at tertiary branches were taken into consideration.

5. Seed weight per plant

Ten plants randomly taken were used for recording seed weight per plant. Seed produced in umbels was weighed using weighing balance.

6. 100 Seed weight (g)

Hundred seeds were taken randomly from the total seeds collected from umbels selected from each replication and weighed by using electronic balance.

7. Germination (%)

On the 14th day of germination (final count), final per cent germination was recorded on the basis of the percentage of the number of normal seedlings emerged from each replicate.

$$\text{Germination (\%)} = \frac{\text{Number of seeds germinated}}{\text{Total number of seeds kept}} \times 100$$

8. Speed of germination

Twenty five seeds of each replication were kept in moist petri-dishes for 14 days and number of seeds germinated each day were recorded.

$$\text{Speed of Germination} = \sum \frac{G_t}{T_t}$$

9. Seedling length (cm)

Ten seedlings per replication were selected randomly and mean length was calculated. Seedling length was measured from tip of uppermost leaf till top of longest root using a centimeter scale.

10. Seedling dry weight (g)

Ten plants used for seedling length were taken for estimation of dry weight. The seedlings were oven-dried at 60 C for one day and its weight was recorded. The root and shoot were separated and their dry weights were recorded.

11. Seedling vigour index

Germinated seedlings were assessed for vigour index (VI). The root and shoot length of germinated seedlings were measured and vigour index was calculated by using this formulae.

$$\text{Seedling vigour index I} = \text{Germination (\%)} \times \text{shoot length}$$

$$\text{Seedling vigour index II} = \text{Germination (\%)} \times \text{seedling dry weight}$$

3.5 Statistical analysis

The data recorded were subjected to following statistical analysis:

3.5.1 Analysis of variance

Analysis of variance was carried out for various parameters using computer programme CPCS 1. Factorial split plot design was used and comparisons were made at 5% level of significance.

3.5.2 Genotype and environment interaction as described by GGE Biplot, Romagosa and Fox (1993)

Regarding agricultural problems due to G x E interactions, there exist two basic options, one aimed at the genotypes and the other at the environments (Ceccarelli 1989, Simmonds 1991, Zavala *et al* 1992). The first option is to select a high yielding, widely adapted genotype that is outstanding throughout the growing region of interest. The second option which is particularly relevant when the first fails, is to sub-divide the growing region into several relatively homogeneous macro - environments (with little interaction within each macro-environment) and then breed and recommend varieties for each. The advantages of the GGE Biplot model or its variants are that they use overall fitting, impose no restrictions on the multiplicative terms and result in least square fit (Freeman 1990). Within limits, any model may be expected to fit the data from which it was derived. However, the GGE Biplot model has a good chance of being able to predict the performance of cultivars in similar sites and future years (Gauch 1988).

The GGE Biplot model has found more use recently since it incorporated both the classical additive main effects model for GXE interaction and the multiplicative components into an integrated least square analysis and thus become more effective in selection of stable genotypes (Nassir and Ariyo 2011, Yan and Hunt 2001, Ariyo and Ayo Vaughan 2000, Taye *et al* 2000, Haji and Hunt 1999, Ariyo 1998, De Cauwer and Ortiz 1998, McLaren and Chaudhary 1994, Crossa *et al* 1991). This technique is also called FANOVA (Gollob 1968).

Model diagnosis

GGE Biplot is a model family rather than a single model (Hongyu *et al* 2014). Consequently, Model diagnosis is required to determine which member of this model family is the best for given dataset and research purpose (Gauch 2006 and Gauch 2013).

This model combines two methods: Analysis of variance and singular value decomposition in a unique model, additive components for the main effect of genotype (g_i), environment (e_j) and multiplicative components for the interaction effect (ge_{ij}) (ij) (Gauch 2013, Gauch *et al* 2011, Arciniegas *et al* 2010, Garcia and Dias 2009, Dias and Krzanowski 2003, Gauch 1992).

Model equation for the i^{th} genotype in the j^{th} environment in r blocks (repetition) is:

$$Y_{ijr} = \mu + g_i + e_j + b_r(e_j) + \sum_{k=1}^n \lambda_k \alpha_{ik} \gamma_{jk} + \rho_{ij} + \varepsilon_{ij}$$

Where, Y_{ijr} is the phenotypic trait (e.g. yield) of genotype i in environment j for replicate r , μ is the grand mean, g_i are the genotypic main effect as deviation from μ , e_j are the environment main effect as deviation from μ , λ_k is the singular value for the Interaction Principal Components (IPC) axis k , α_{ik} and γ_{jk} are the genotype and environment IPC Scores (i.e the left and right singular vector) for axis k , $b_r(e_j)$ is the effect of the block r within the environment j , r is the number of blocks, ρ_{ij} is the residual containing all multiplicative terms not including in the model; n is the number of axis or principal component (PC) retained by the model, and ε_{ijr} is the experiment error, assumed independent with identical distribution $\varepsilon_{ij} \sim N(0, \sigma^2/r)$.

In the ANOVA, the total variation is partitioned into three sources, namely genotypes, environment and G x E interactions. In this regard, a review of Purchase (1997) revealed that, in most yield trials, the proportion of sum of squares due to differences among sites ranged from 80 to 90% and the variation due to G x E interactions is often larger than that of the genotypes. Hence, GGE Biplot model can produce biplot graphs, which display the variability of genotypes and G x E interactions (Issa 2013).

Interpretation of biplots

To have a better discussion on the biplots resulted from the GGE Biplot analysis we must consider the following points (Rashidi *et al* 2013 and Kempton 1984):-

- (i) The center of biplot shows the mean of a genotype or an environment.
- (ii) A long distance of a genotype (or an environment) from the center of biplot indicates a large interaction with that genotype (or environment).
- (iii) The long length of a genotype on the environmental vector reveals more deviation from the mean and vice versa.
- (iv) The angle between the vectors of a genotype and an environments shows that the interaction is positive or negative.

Identifying high yielding stable genotypes (GGE biplot 1)

GGE Biplot model combines the analysis of variance for main effects of G and E with principal component analysis of GEI. It has proven useful in understanding complex GEI (Agyeman *et al* 2015). In the GGE biplot 1 additive main effects or mean are shown along the abscissa and the ordinate represents the first IPCA or multiplicative interaction, stability was interpreted from the ordinate axis, with scores close to the zero considered as the stable genotypes and environments (Farias *et al* 2016). The interpretation of a biplot assay is that if main effects have IPCA score close to zero, it indicates negligible interaction effects and when a genotype and an environment have the same sign on the IPCA axis, their interaction is

positive; if different, their interaction is negative. If points of environments are more scattered than the point for genotypes indicating that variability due to environments is higher than that due to genotypes difference which is in complete agreement of stability ANOVA (Farshadfar and Farhadi 2014). Adaptability was interpreted from the abscises axis, where the means of genotypes and environments are plotted (Gauch and Zabler 1988). According to the GGE Biplot model, the genotypes which are characterized by means greater than grand mean and the IPCA score nearly zero are considered as generally adaptable to all environment. Environments which are characterized by means greater than grand mean and the IPCA score nearly zero are considered as stable environments and suitable for selecting the wide range of genotypes (Kumar *et al* 2014). Genotypes that group together have similar adaptation while environments which group together influences the genotypes in same way (Akter *et al* 2014 and Kempton 1984).

However, the genotype with high mean performance and with large value of IPCA score are consider as having specific adaptability to the environments.

GGE Biplot 2

GGE Biplot 2 shows a polygon connecting the genotypes that are furthest from the biplot point of origin. These genotypes have the highest vectors in their respective directions; the vector length and direction represents the extension of the genotypes response to the tested environments. All other genotypes are contained within the polygon and have smaller vectors, i.e., they are less sensitive to interaction with the environment in each sector (Agyeman *et al* 2015, Kandus *et al* 2010, Yan and Rajcan, 2002). The perpendicular lines from the center of biplot intersect the sides of the polygon creating several sectors which cause the environments to fall one of these sectors. Criteria for the formation of mega-environments are: significant differences between the genotypes in different environments; and variation, which is observed graphically, in one group must be significantly greater than in the other (Yan and Rajcan, 2002). Hence a corner or vector genotype is best or winner genotype in one or more environments falling in the sector. When genotypes give rise to polygon vertices, but do not contain any clustered environments, indicates genotypes poor performance in all the environments or not the best in any of the environment.

CHAPTER IV

RESULTS AND DISCUSSION

The results obtained during the course of experimentation are presented in this chapter with the help of tables and graphs. The results have been interpreted and supported with the help of previous research findings.

4.1 Morphological characterization of carrot genotypes

4.1.1 Plant height (cm)

Among both the locations L1 (Ludhiana) and L2 (KVK Langroya), the plant height of carrot was significantly better in L1 (75.67 cm) as compared to L2 (71.47 cm). Date of sowing also had significant effect on plant height. D4 (First week on November) showed significantly higher plant height which was statistically at par with D1 (First week of September) and significantly better over D2 (Last week of September) and D3 (Second week of October). The plant height differed significantly due to genotypes. It ranged from 66.96 to 79.77 cm. Genotype 10 (P-35) showed the maximum (79.77 cm) plant height which was statistically at par with genotype 11 (P-41) having 78.73 cm and genotype 2 (P-4) with 75.77 cm plant height which were significantly better over all other genotypes. Bhatia *et al* (2002) observed more plant height in HCER-1 (105.8 cm) followed by Jind Collection (99.6 cm) and HC-227 (97.9 cm) under different date of sowings.

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for plant height was given in Figure 4.1(a & b). At location 1 (PAU, Ludhiana) shown in Fig 4.1 (a), the genotypes P-28 (G8), PCO-6 (G13), P-41 (G11) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely P-41 (G11) and Carrot Early Nantes (G15) had maximum plant height exhibiting adaptation to all four environments and therefore categorized as generalists. The genotypes P-18 (G6) and P-3 (G1) were poor performers across the four plantings (four environments) due to minimum plant height. The genotype P-35 (G10) had maximum plant height and was suitable for unfavorable environment (lower IPCA 1 value) and also had highest negative interaction with environment coupled with maximum plant height that showed its moderate response to environmental changes. The genotypes P-5 (G3), Pusa Meghali (G16) and P-3 (G1), P-23 (G7) & P-4 (G2) were on the same horizontal axis showed that these genotypes had similar G×E interaction but vary appreciably for plant height. From this study, it was concluded that maximum plant height was observed in P-35 (G10) and minimum in P-18 (G6). Based on Biplot 1 at location 1 (PAU, Ludhiana), E₂ was the most stable environment because it had lower value on IPCA 1 axis and therefore exhibited least contribution toward the G×E interaction. The E₄ had the maximum plant height than other

Table 4.1: Effect of locations, date of sowings and genotypes on plant height (cm), shoot weight (g), shoot length (cm), root length (cm) and root weight (g) of carrot

		Plant height (cm)	Shoot weight (g)	Shoot length (cm)	Root length (cm)	Root weight (g)
Locations	L1	75.67	35.97	52.63	23.03	85.90
	L2	71.47	30.92	45.00	26.47	92.44
	CD (5%)	0.95	0.30	0.65	0.59	0.48
Date of sowings	D1	78.66	29.01	58.84	19.82	75.17
	D2	65.27	24.09	42.56	22.70	75.73
	D3	70.49	34.42	43.98	26.50	99.92
	D4	79.85	46.26	49.87	29.98	105.86
	CD (5%)	1.35	0.43	0.92	0.84	0.68
Genotypes	G1	71.99	30.06	48.33	23.66	88.31
	G2	75.77	31.43	52.15	23.61	91.02
	G3	73.12	37.79	51.04	22.08	84.55
	G4	73.09	42.18	50.08	23.00	82.28
	G5	73.32	32.44	48.07	25.25	82.91
	G6	66.96	30.84	44.84	22.12	82.42
	G7	70.36	34.97	46.67	23.69	91.82
	G8	69.43	28.07	45.31	24.12	90.25
	G9	73.22	38.22	46.10	27.11	94.61
	G10	79.77	27.84	52.09	27.67	86.64
	G11	78.73	32.40	53.12	25.61	81.75
	G12	72.60	33.30	48.13	24.47	91.73
	G13	72.40	34.59	49.19	23.20	95.36
	G14	74.88	38.14	49.63	25.25	99.81
	G15	75.00	32.48	49.31	25.68	91.83
	G16	74.46	33.10	47.10	27.35	84.08
	G17	75.54	30.75	48.65	26.88	96.51
	CD (5%)	1.91	0.87	0.95	0.81	1.53
	Locations × Date of sowings	1.91	0.61	1.30	NS	0.97
	Locations × Genotypes	1.71	1.24	1.34	1.15	2.16
	Date of sowings × Genotypes	2.43	1.75	1.90	1.62	3.06
Locations × Date of sowings × Genotypes	3.43	2.48	2.69	2.30	4.33	

environments (sowings) and lowest IPCA 1 score revealed that E_1 was good test site for selecting the genotypes that were specifically adapted to unfavourable environment but it also has poor mean performance.

The GGE Biplot 1 performance of genotypes and environments for plant height of location 2 is illustrated in Fig. 4.1 (b). The genotypes P-18 (G6), PCO-6 (G13), Arka Suraj (G17) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-5 (G3), Pusa Meghali (G16) and Carrot Early Nantes (G15) had maximum plant height exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-18 (G6) and P-28 (G8) was poor performers across the four plantings (four environments) due to minimum plant height. The genotype Carrot Early Nantes (G15) had maximum plant height and was suitable for unfavorable environment (lower IPCA 1 value) and also had highest negative interaction with environment coupled with maximum plant height that showed its moderate response to environmental changes. The genotypes P-16 (G4), P-29 (G9) and P-3 (G1), P-23 (G7) & P-4 (G2) were on the same horizontal axis showed that these genotypes had similar G×E interaction but vary appreciably for plant height. From this study, it was concluded that maximum plant height were observed in P-35 (G10) and minimum plant height obtained in genotype P-18 (G6). Based on Biplot 1 of location 1 (PAU, Ludhiana), E_2 was the most stable environment because it had lower value on IPCA 1 axis and therefore exhibited least contribution toward the G×E interaction. The E_4 had the maximum plant height than other environments (sowings) and lowest IPCA 1 score revealed that E_1 was good test site for selecting the genotypes that were specifically adapted to unfavourable environment but it also has poor mean performance.

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.2 c of GGE Biplot. A polygon connecting the P-3 (G1), P-18 (G6), Pusa Meghali (G16), P-17 (G5) and P-35 (G10) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E_1 , E_2) included in one single environment and E_3 & E_4 lied in other mega environment while other four mega environments did not include any environment. The genotype P-35 (G10) was better adapted to E_4 and E_3 while P-3 (G1) was well adapted to E_1 . The E_2 considered stable environment as it located near to the origin of the polygon. The genotypes PCO-4 (G12) and PCO-6 (G13) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as

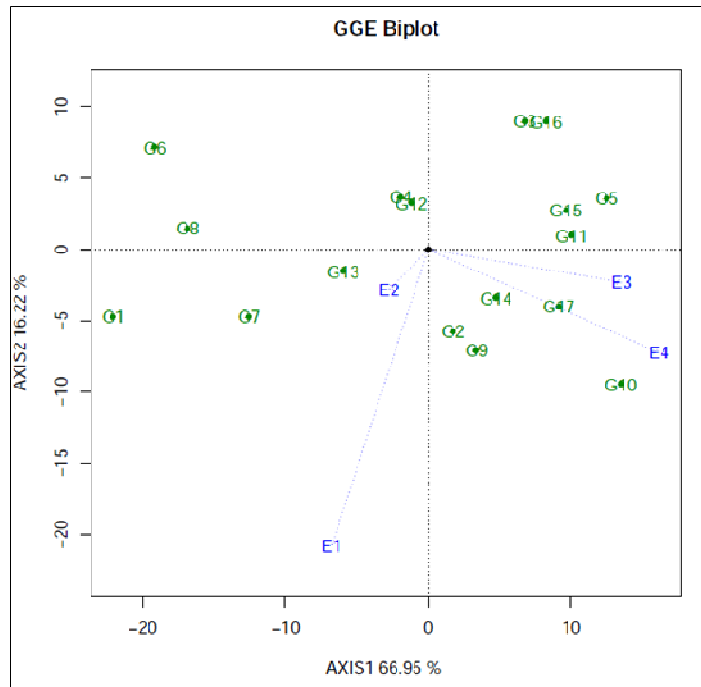


Fig. 4.1 (a) GGE Biplot 1 for plant height of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

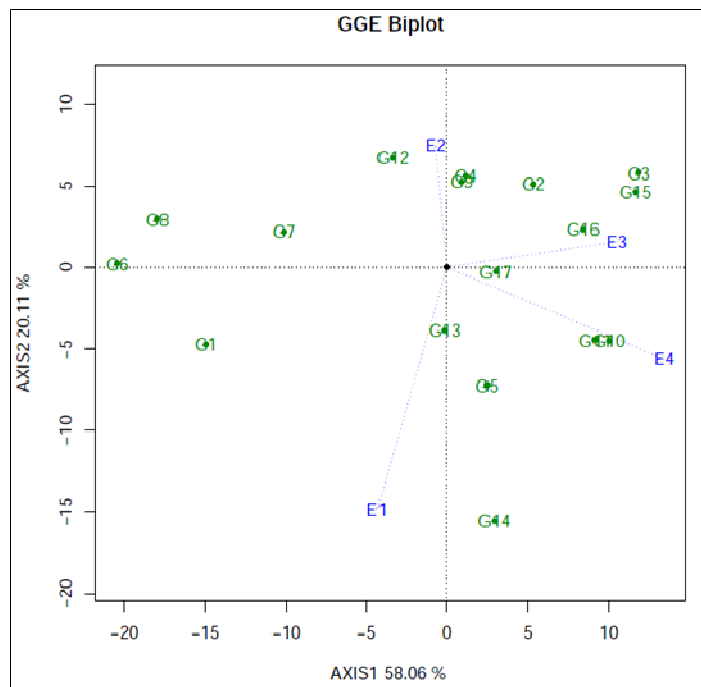


Fig. 4.1 (b) GGE Biplot 1 for plant height of carrot of 17 genotypes in 4 environments at location L1 (KVK, Langroya)

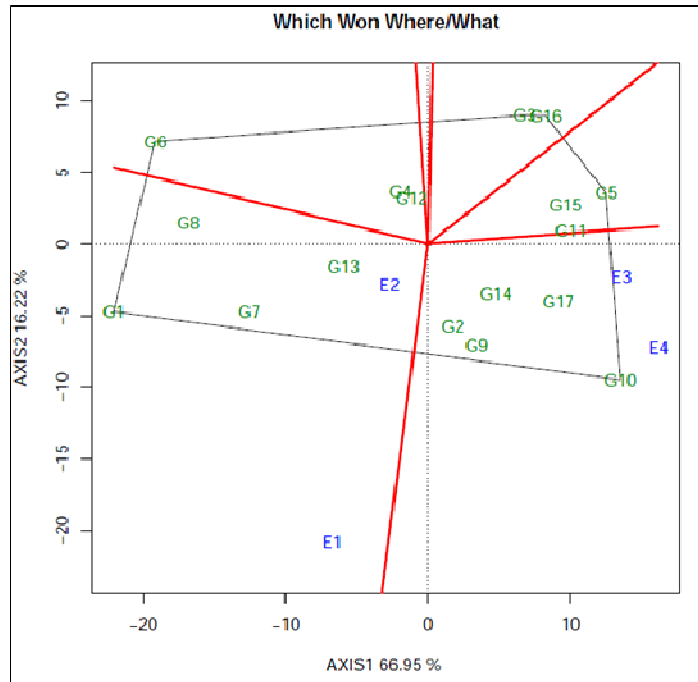


Fig 4.1 (c) Which Won Where GGE Biplot for plant height of carrot showing the interaction of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

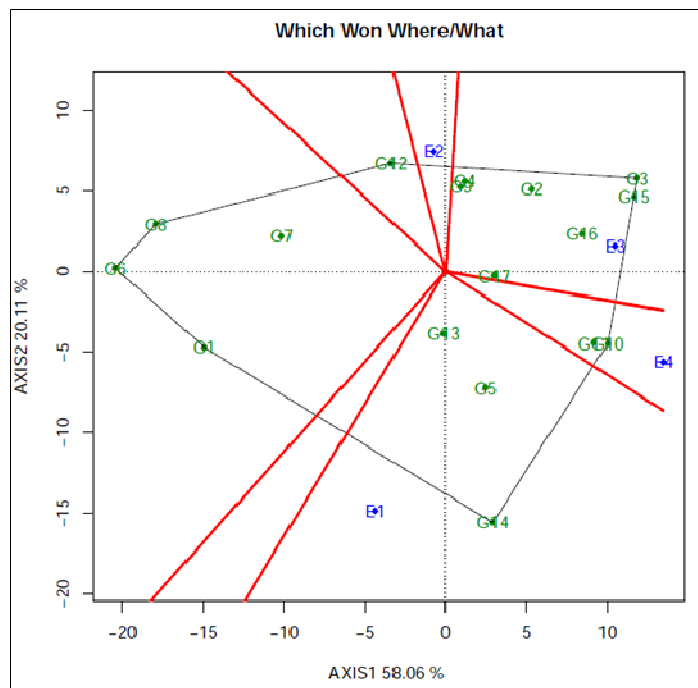


Fig 4.1 (d) Which Won Where GGE Biplot for plant height of carrot showing the interaction of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

specific G×E interaction at two locations is represented in Figure 4.2 d of GGE Biplot. A polygon connecting the P-3 (G1), P-18 (G6), Pusa Meghali (G8), P-17 (G12), P-35 (G3), P-35 (G10) and Carrot Nantes (G14) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₂, E₃) included in one single environment and E₁ & E₄ lied in different mega environments while other four mega environments did not include any environment. The genotype P-35 (G10) was better adapted to E₄ and E₃ while P-3 (G1) was well adapted to E₁. The E₂ considered stable environment as it located near to the origin of the polygon. The genotypes PCO-4 (G12) and Arka Suraj (G17) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.1.2 Shoot weight (g)

Between the location L1 and L2, the shoot weight of carrot was significantly higher in L1 (35.97) as compared to L2 (30.92 cm). Date of sowings also had significant effect on shoot weight. D4 (First week on November) showed significantly higher shoot weight which was statistically better than D3 (First week of September), D2 (Last week of September) and D1 (Second week of October). The shoot weight differed significantly due to genotypes. It ranged from 42.18 to 27.84 cm Genotype 4 (P-16), genotype 5 (P-17) and genotype 3 (P-5) showed the maximum (42.18 cm) shoot weight which was significantly better over all other genotypes shown in Table 4.1.

Yadav *et al* (2009) found that the shoot weight ranges from 60.0 to 78.3 g with maximum root weight and total root yield in Deshi red in different environments. The studies of Tewatia *et al* (2000) also revealed that root length, root weight and root-shoot ratio increased while shoot weight and root diameter decreased at different sowing dates. The mean performance of variety HC-1 was significantly high for root length, shoot length, root diameter, root weight and root-shoot ratio in all the sowing dates. For root length, significantly better performing lines were HCP-160 in August sowing, HCP-4 in September sows and HC-2, HC-1 on October sowing. For root diameter, the better performing lines were HCB-22-1 in September sowing. Jind collection, HCP-1, HCP-206 showed significantly better root-shoot ratio in October sowing. The mean performance of HC-227, HC-2 and HCP-160 for shoot weight was significantly better than the highest yielding control.

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for shoot weight was given in Figure 4.2 (a& b). At location 1 (Ludhiana) shown in Fig 4.2 (a) the genotypes P-29(G9), PCO-6 (G13), P-41 (G11) showed stable performance as they had lower

coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Nantes (G14) and P-16 (G4) had maximum shoot weight exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-4 (G2) and P-28 (G8) was poor performers across the four plantings (four environments) due to minimum shoot weight.

At location 2 (KVK Langroya) shown in Fig 4.2 (b) the genotypes P-28 (G8), Arka suraj (G17), PCO-4 (G12), PCO-6 (G13), P-23 (G7) and P-29 (G9) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-17 (G5) and P-5 (G3) had maximum shoot weight exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-3 (G1) was poor performers across the four plantings (four environments) due to minimum shoot weight.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.2 c & d of GGE Biplot. At location 1 a polygon connecting the P-3 (G1), P-4 (G2), P-16 (G4), P-5 (G3), Pusa Meghali (G16), P-35 (G10) and P-28 (G8) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₂, E₃) included in one single environment and E₁ & E₄ lied in other mega environment while other four mega environments did not include any environment. The genotype P-16 (G4) was better adapted to E₄ while P-5 (G3) was well adapted to E₃.

At location 2 a polygon connecting the P-3 (G1), P-28(G8), P-35(G10), P-41 (G11), P-5 (G3), P-29 (G19), P-16 (G4) and P-3 (G1) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₄, E₃) included in one single environment and E₁ & E₂ lied in other mega environment while other four mega environments did not include any environment. The genotype P-5 (G3) was better adapted to E₃ while P-16(G4) was well adapted to E₃.

4.1.3 Shoot length (cm)

As shown in Table 4.1, shoot length of carrot at both the locations L1 (Ludhiana) and L2 (KVK Langroya) was recorded and shoot length was significantly better in L1 (52.63 cm) in comparison with L2 (45.00 cm). Date of sowings also had significant effect on shoot

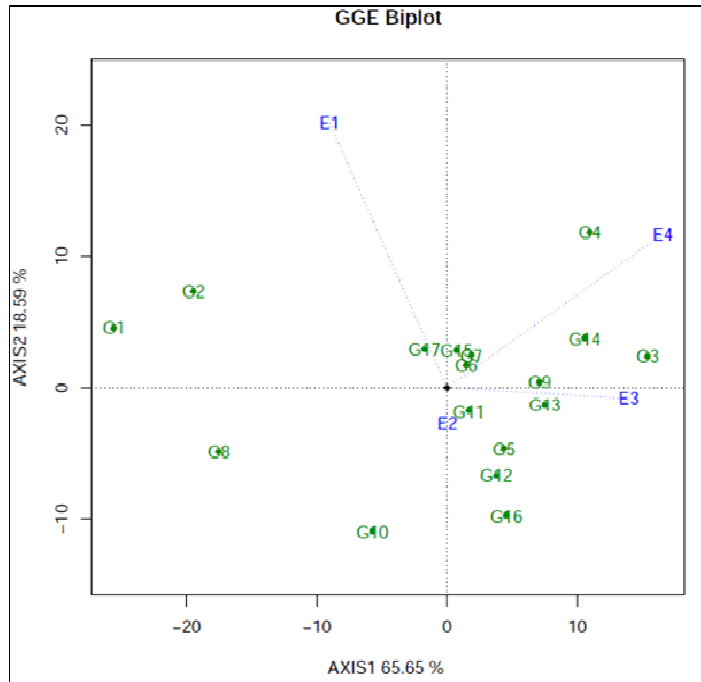


Fig. 4.2 (a) GGE Biplot 1 for shoot weight of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

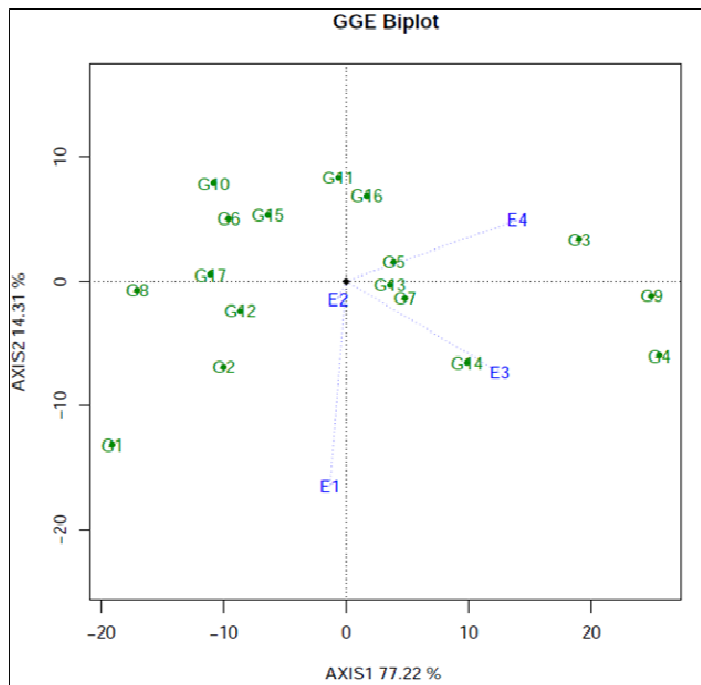


Fig. 4.2 (b) GGE Biplot 1 for shoot weight of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

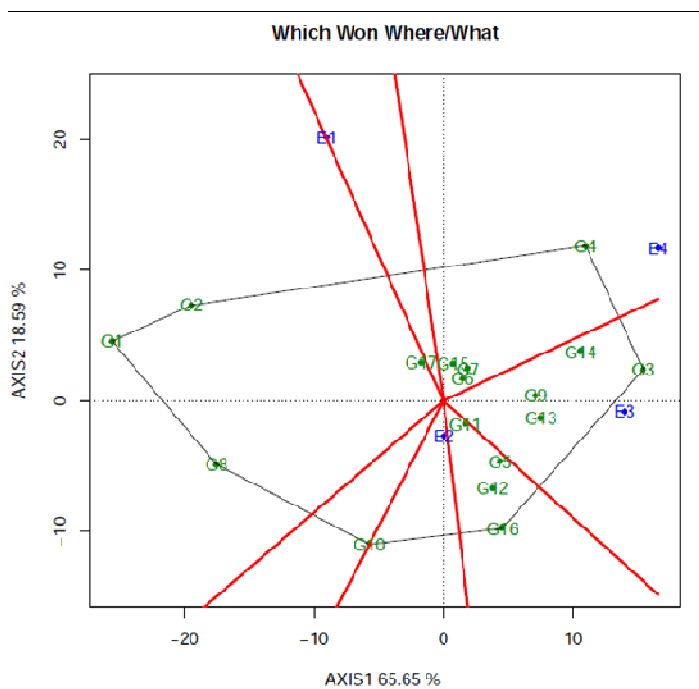


Fig. 4.2 (c) Which won where/what GGE Biplot for shoot weight of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

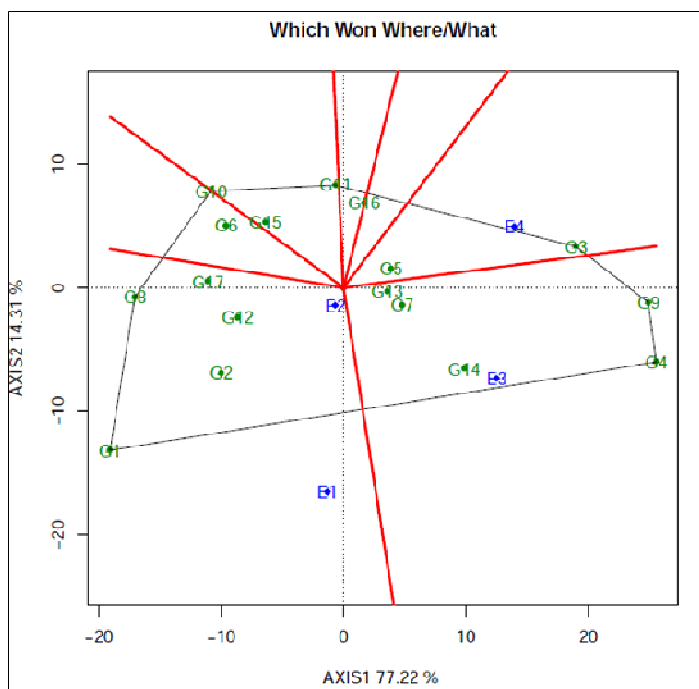


Fig. 4.2 (d) Which won where/what GGE Biplot for shoot weight of carrot of 17 genotypes in 4 environments at location L1 (KVK, Langroya)

length. D1 showed significantly higher shoot length than D4, D3 and D2. The shoot length of carrot differed significantly due to genotypes. It ranged from 53.12 to 44.84 cm Genotype 11 (P-41) showed the maximum (53.12 cm) shoot length which was statistically at par with genotype 10 (P-35) having 52.09 cm and genotype 2 (P-4) having 52.15 cm shoot length and significantly better over all other genotypes. Similar findings of Tewatia *et al* (2000) showed variation for the top height 55.16-62.60 cm. Panda *et al* (1994) reported highest shoot length in Selection-5 (52.28 cm) followed by Early Nantes (48.55 cm) and Chantaney (50.74 cm).

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for shoot length was given in Figure 4.3 a & b. At location 1 (PAU, Ludhiana) shown in Fig 4.3 (a) the genotypes P-28(G8), P-18 (G6), P-16 (G4) and P-5 (G3) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-35 (G10) and P-4 (G2) had maximum shoot length exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype Carrot Nantes (G14) and Pusa Meghali (G16) was poor performers across the four plantings (four environments) due to minimum shoot length.

At location 2 (KVK Langroya) shown in Fig 4.3 (b) the genotypes P-18 (G6), P-28 (G8), P-35 (G10), P-5 (G2), P-16(G4) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Early Nantes (G15) had maximum shoot length exhibiting adaptation to all four environments and therefore categorized as generalists.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.3 (c & d) of GGE Biplot. At location 1 a polygon connecting the P-3 (G1), P-29(G9), Carrot Nantes (G14), P-5 (G3), P-41 (G11), Carrot early nantes (G15) and Pusa Meghali (G16) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₁, E₂) included in one single environment and E₃& E₄ lied in other mega environment while other four mega environments did not include any environment. The genotype P-29 (G9) was better adapted to E₁.

At location 2 a polygon connecting the P-3 (G1), P-28 (G8), P-18(G6), PCO-4 (G12), Carrot early nantes (G15), P-5 (G3) and P-41 (G11) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were

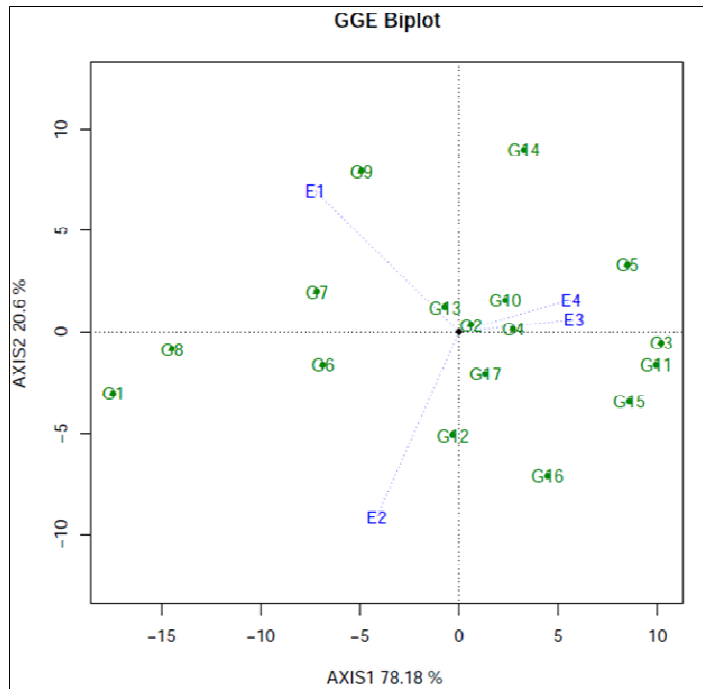


Fig. 4.3 (a) GGE Biplot 1 for shoot length of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

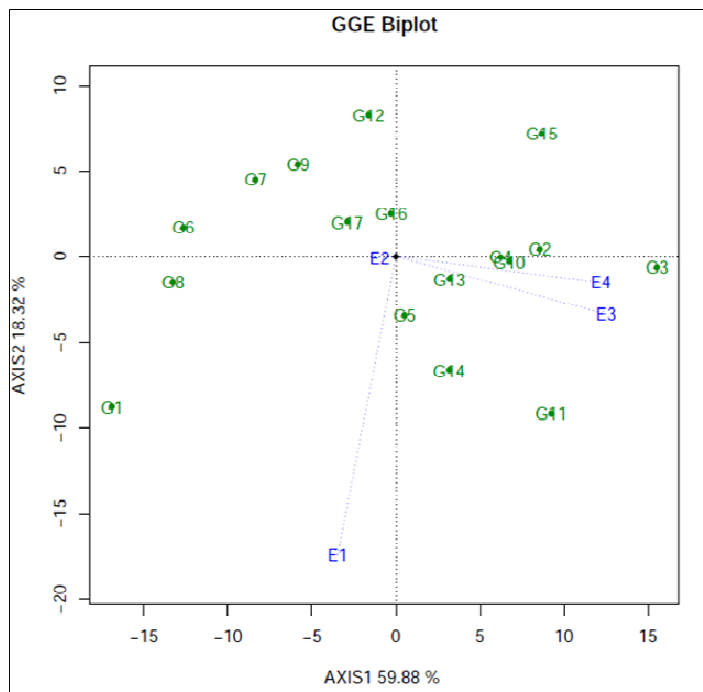


Fig. 4.3 (b) GGE Biplot 1 for shoot length of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E_1E_2) included in one single environment and E_3 & E_4 lied in other mega environment while other four mega environments did not include any environment. The genotype P-5 (G3) was better adapted to E_3 .

4.1.4 Root length (cm)

Table 4.1 shows the effects of both the locations L1 (Ludhiana) and L2 (KVK Langroya), Date of sowings and genotypes. The root length of carrot was significantly better in L2 (26.47 cm) as compared to L1 (23.03 cm). Date of sowings also had significant effect on root length. D4 showed significantly higher root length (29.98 cm) significantly better over D3, D2 and D1. Genotypes differed significantly in root length. It ranged from 27.67 to 22.08 cm Genotype 10 (P-35) showed the maximum (27.67 cm) root length which was statistically at par with genotype 9 (P-29) with 27.11 cm and genotype 16 (Pusa Meghali) with 27.35 cm root length which were significantly better over all other genotypes.

Nandal *et al* (2008) also obtained similar results as the root length was influenced by the Date of sowings. They recorded maximum length of roots in November sown crops.

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for root length was given in Figure 4.4 (a & b). At location 1 (PAU, Ludhiana) shown in Fig 4.4 (a) the genotypes Arka Suraj (G17), P-16 (G4), P-3 (G1) and PCO-6 (G13) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, PCO-4 (G12) and P-4 (G2) had maximum root length exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-35 (G10) was poor performers across the four plantings (four environments) due to minimum root length.

At location 2 (KVK Langroya) shown in Fig 4.4 (b) the genotypes Arka suraj (G17), P-17 (G5), PCO-4 (G12), P-28 (G8), showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-23 (G7) and PCO-6 (G13) had maximum root length exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-35 (G10) was poor performers across the four plantings (four environments) due to minimum root length.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.4 c & d of GGE Biplot. At location 1 a polygon connecting the P-35 (G10), P-17(G5), P-5 (G3), P-18 (G6), P-41 (G11) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme

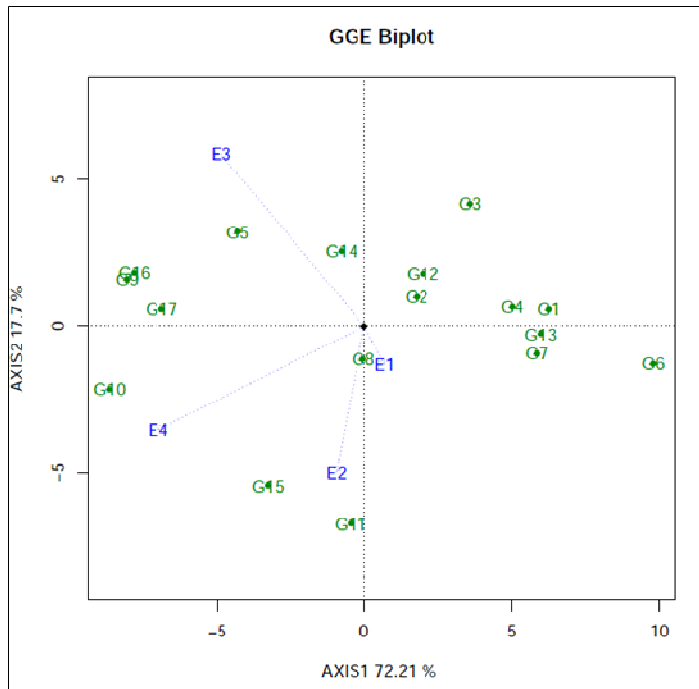


Fig. 4.4 (a) GGE Biplot 1 for root length of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

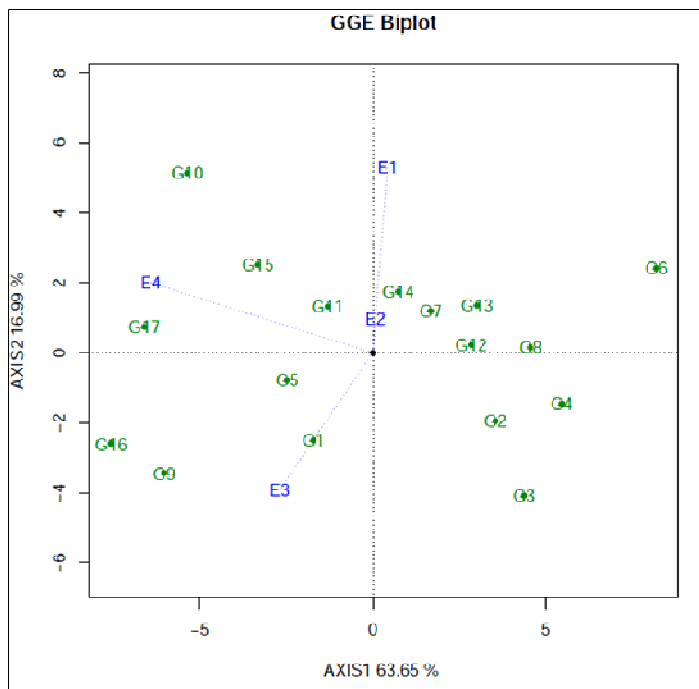


Fig. 4.4 (b) GGE Biplot 1 for root length of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

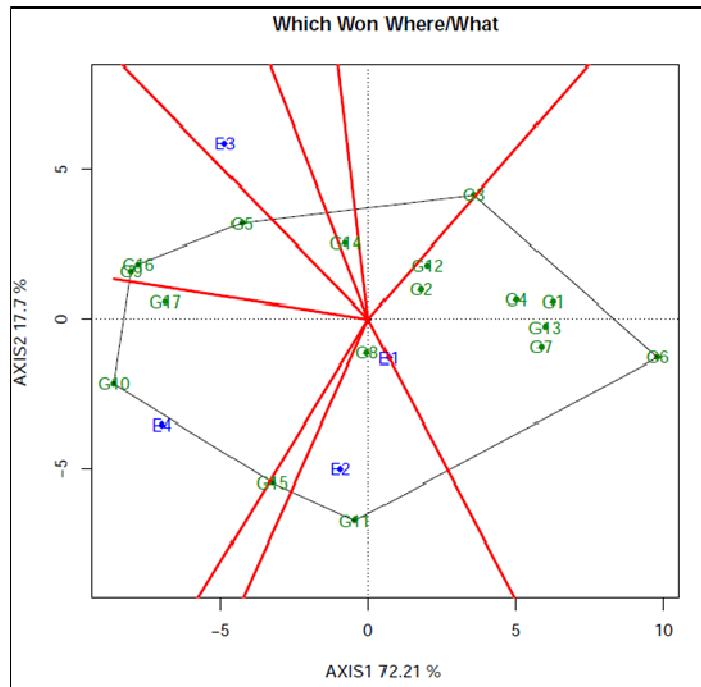


Fig. 4.4 (c) Which won where/what GGE Biplot 1 for root length of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

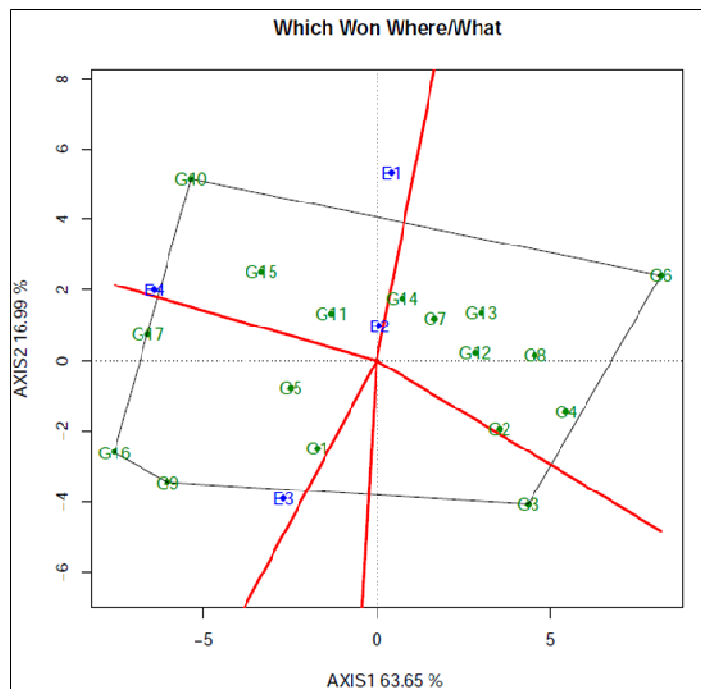


Fig. 4.4 (d) Which won where/what GGE Biplot 1 for root length of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₂, E₃ and E₄) included in one single environment and E₁ lied in other mega environment while other four mega environments did not include any environment. The genotype P-17 (G₅) was better adapted to E₃ while P-41(G₁₁) was well adapted to E₂.

At location 2 a polygon connecting the P-35 (G₁₀), P-18 (G₆), P-5 (G₃), P-29 (G₁₉), P-29 (G₉) and Pusa Meghali (G₁₆) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₄, E₃) included in one single environment and E₁ & E₂ lied in other mega environment while other four mega environments did not include any environment. The genotype P-35 (G₁₀) was better adapted to E₄ while P-29(G₉) was well adapted to E₃.

4.1.5 Root weight (g)

The perusal of the data of the table 5 indicates effects of both the locations L1 (Ludhiana) and L2 (KVK Langroya), Date of sowings on root weight of carrot genotypes. Root weight of carrot was significantly better in L2 (92.44 g) as compared to L1 (85.90 g). Date of sowings also had significant effect on root weight. D4 (First week on November) showed significantly more root weight (105.86) and was significantly better over D1 (First week of September), D2 (Last week of September) and D3 (Second week of October). The root weight differed significantly due to genotypes. It ranged from 99.81 to 81.75 g. Genotype 14 (Carrot Nantes) showed the maximum (99.81 g) which was statistically at par with genotype 17 (Arka suraj) root weight and significantly better over all other genotypes as shown in table 4.1.

Similarly, Bhatia *et al* (2002) also reported that root weight varied between 149.30-151.14 g and reported that HC-153 had maximum root weight of 154.00 g followed by HC-160 (151.14 g) and HCP-227 (149.30 g). Tewatia *et al* (2000) studied 26 lines of carrot including check varieties which showed significant differences for root weight at all Date of sowing.

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for root weight was given in Figure 4.5 (a & b). At location 1 (PAU, Ludhiana) shown in Fig 4.5 (a) the genotypes P-5 (G₃), P-16 (G₄), P-3 (G₁) and P-18(G₆) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E

interaction. The genotypes namely, Arka Suraj (G17) and Carrot early nantes (G15) had maximum root weight exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-41 (G11) and P-17 (G5) was poor performers across the four plantings (four environments) due to minimum root weight.

At location 2 (KVK Langroya) shown in Fig 4.5 (b) the genotypes P-18 (G6), P-17 (G5), P-4 (G2), P-29 (G9), and Carrot Nantes(G14) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, PCO-4 (G12) and Carrot early nantes (G15) had maximum root weight exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-41 (G11) and Pusa Meghali (G16) was poor performers across the four plantings (four environments) due to minimum root weight.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.5 c & d of GGE Biplot. At location 1 a polygon connecting the P-41 (G11), PCO-4(G12), Carrot Nantes(G14), P-17 (G5) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₁, E₂ and E₃) included in one single environment and E₄ lied in other mega environment while other four mega environments did not include any environment.

At location 2 a polygon connecting the P-41 (G11), Carrot early nantes (G15), Arka Suraj (G17), PCO-6 (G13), Pusa Meghali (G16) and furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₁, E₂ and E₃) included in one single environment and E₄ lied in other mega environment while other four mega environments did not include any environment.

4.1.6 Root girth (cm)

Between the two locations i.e. L1 (Ludhiana) and L2 (KVK Langroya), the root girth of carrot was significantly better in L2 (4.01) as compared to L1 (3.53 cm). Date of sowings also had significant effect on root girth. D4 (First week on November) showed significantly higher plant height which was significantly better over D1 (First week of September), D2 (Last week of September) and D3 (Second week of October). The root girth differed significantly due to genotypes. It ranged from 3.31 to 4.34 cm Genotype 14 (Carrot Nantes)

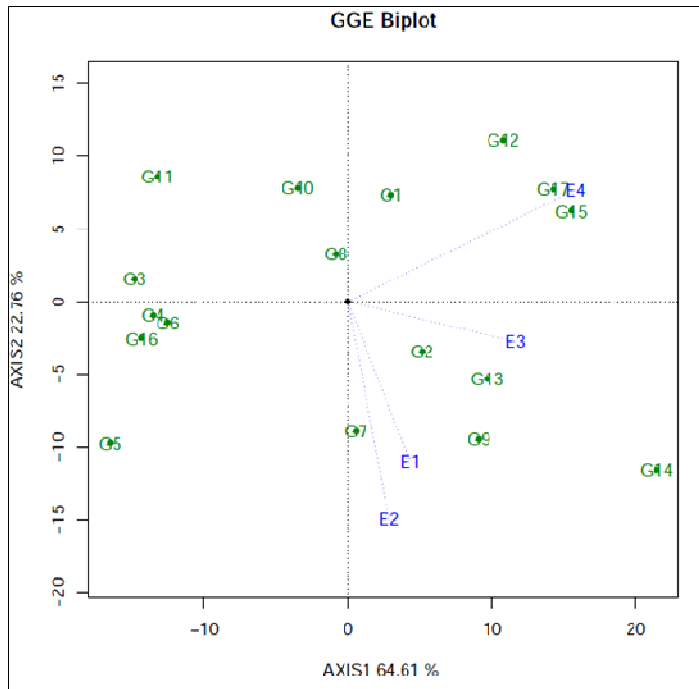


Fig. 4.5 (a) GGE Biplot 1 for root weight of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

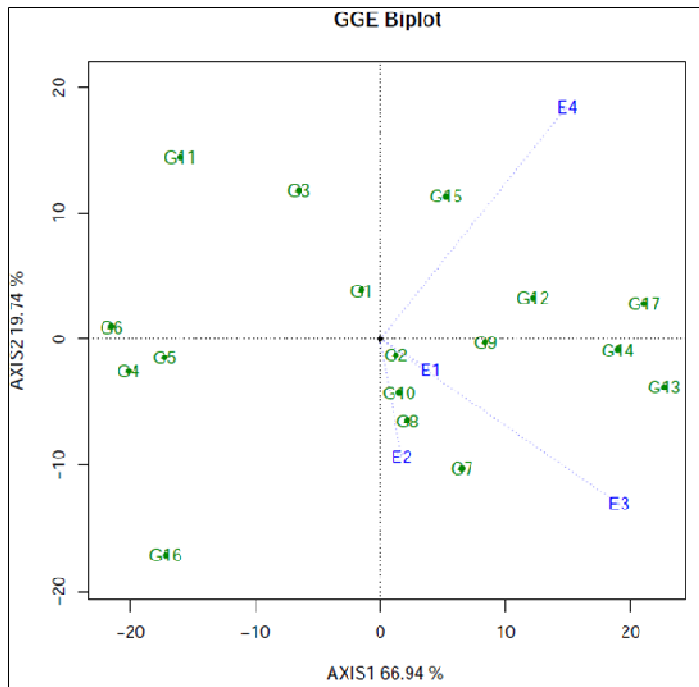


Fig. 4.5 (b) GGE Biplot 1 for root weight of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

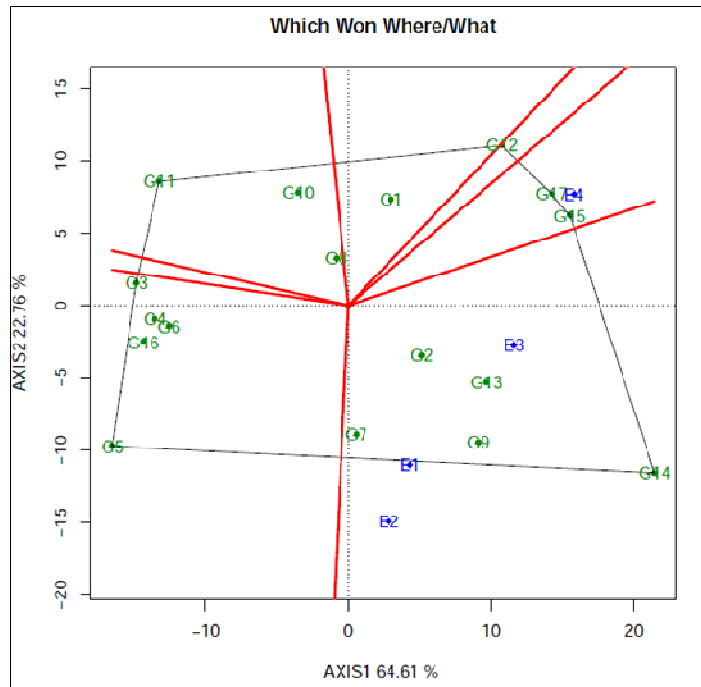


Fig. 4.5 (c) Which won where/what GGE Biplot 1 for root weight of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

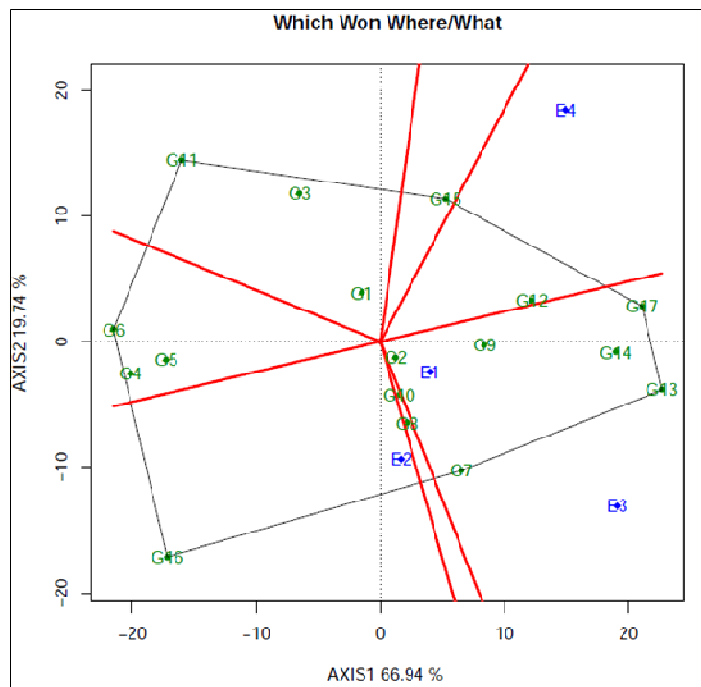


Fig. 4.5 (d) Which won where/what GGE Biplot 1 for root weight of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

showed the maximum (4.34 cm), genotype 13(PCO-6) and genotype 15 (Carrot Early Nantes) also had maximum root girth which was significantly better over all other genotypes.

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for root girth was given in Figure 4.6 (a and b). At location 1 (PAU, Ludhiana) shown in Fig 4.6 (a) the genotypes PCO-6 (G13), P-29 (G9), P-4 (G2) and Pusa Meghali (G16) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotype namely, PCO-6 (G12) had maximum root girth exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-41 (G7) was poor performers across the four plantings (four environments) due to minimum root girth.

At location 2 (KVK Langroya) shown in Fig 4.6 (b) the genotypes PCO-6 (G13), P-4 (G2), PCO-6 (G12), showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotype namely, P-18 (G6) and had maximum root girth exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype Carrot Nantes (G14) was poor performers across the four plantings (four environments) due to minimum root girth.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.6 c & d of GGE Biplot. At location 1 a polygon connecting the P-23 (G7), P-18(G6), P-41 (G11), Carrot Nantes(G14) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₁, E₂) included in one single environment and E₃ and E₄ lied in other mega environment while other four mega environments did not include any environment.

At location 2 a polygon connecting the Pusa Meghali (G16), Carrot Nantes(G14), P-35 (G10), PCO-6 (G13),P-16 (G4) and furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₂, E₃ and E₄) included in one single environment and E₁ lied in other mega environment while other four mega environments did not include any environment.

Table 4.2: Effect of locations, date of sowings and genotypes on root girth (cm), core girth (cm), flesh thickness (cm) and days to ist root harvest of carrot.

		Root girth (cm)	Core girth (cm)	Flesh Thickness (cm)	Root Shoot ratio	Days to Ist Root harvest
Locations	L1	3.53	1.23	2.29	2.52	108.59
	L2	4.01	1.63	2.38	3.24	107.91
	CD (5%)	0.22	0.44	0.048	0.43	0.10
Date of sowings	D1	3.71	1.34	2.36	2.73	110.31
	D2	3.74	1.16	2.22	2.80	107.17
	D3	3.78	1.58	2.19	3.18	108.76
	D4	3.87	1.64	2.57	3.21	105.31
	CD (5%)	0.32	0.62	0.67	0.60	0.14
Genotypes	G1	3.49	1.39	2.10	3.20	108.12
	G2	3.75	1.43	2.31	3.02	108.20
	G3	3.31	1.05	2.25	2.53	107.79
	G4	3.73	1.41	2.32	2.13	108.00
	G5	3.79	1.35	2.44	2.77	107.95
	G6	3.83	1.52	2.31	2.88	107.62
	G7	3.99	1.54	2.45	2.78	108.41
	G8	3.87	1.54	2.32	3.30	108.37
	G9	3.80	1.46	2.34	2.71	108.25
	G10	3.92	1.43	2.48	3.28	108.04
	G11	3.36	1.37	1.98	2.71	108.58
	G12	3.73	1.24	2.48	2.85	107.79
	G13	4.01	1.47	2.53	2.95	107.97
	G14	4.34	1.68	2.65	2.75	108.37
	G15	4.00	1.37	2.63	3.00	108.66
	G16	3.51	1.60	1.91	2.77	107.95
	G17	3.67	1.48	2.19	3.34	107.62
	CD (5%)	0.62	0.75	0.94	0.10	0.25
	Locations × Date of sowings	0.45	0.88	0.96	0.86	0.20
	Locations × Genotypes	0.88	0.10	0.13	0.15	0.35
	Date of sowings × Genotypes	0.12	0.15	0.18	0.21	0.50
Locations × Date of sowings × Genotypes	0.17	0.21	0.26	0.30	0.71	

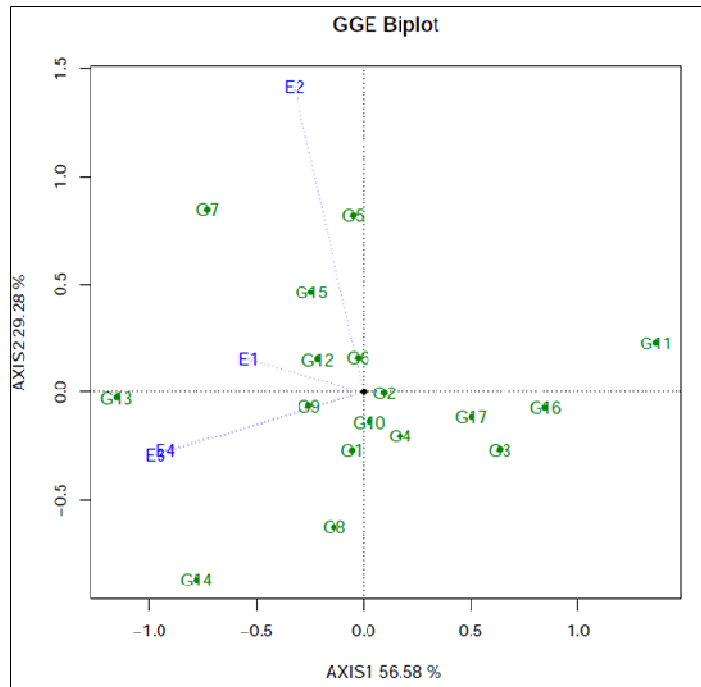


Fig. 4.6 (a) GGE Biplot 1 for root girth of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

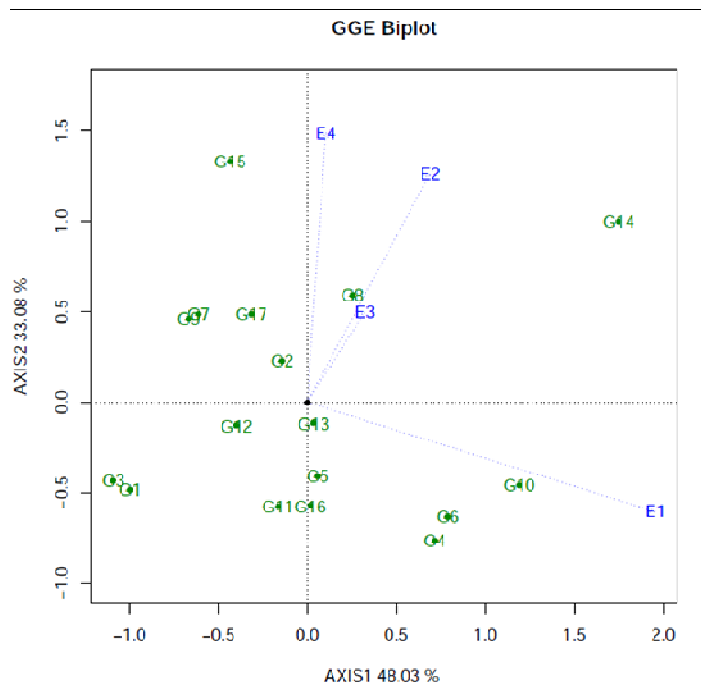


Fig. 4.6 (b) GGE Biplot 1 for root girth of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

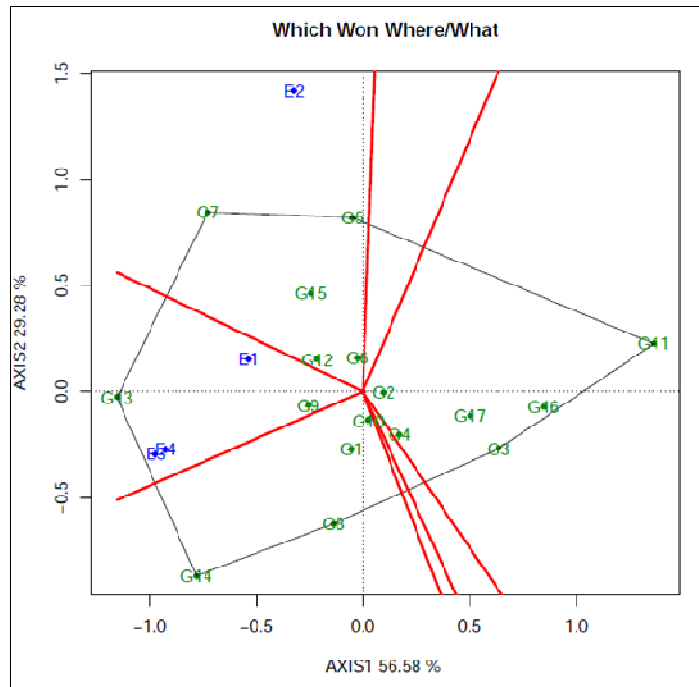


Fig. 4.6 (c) Which won where/what GGE Biplot 1 for root girth of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

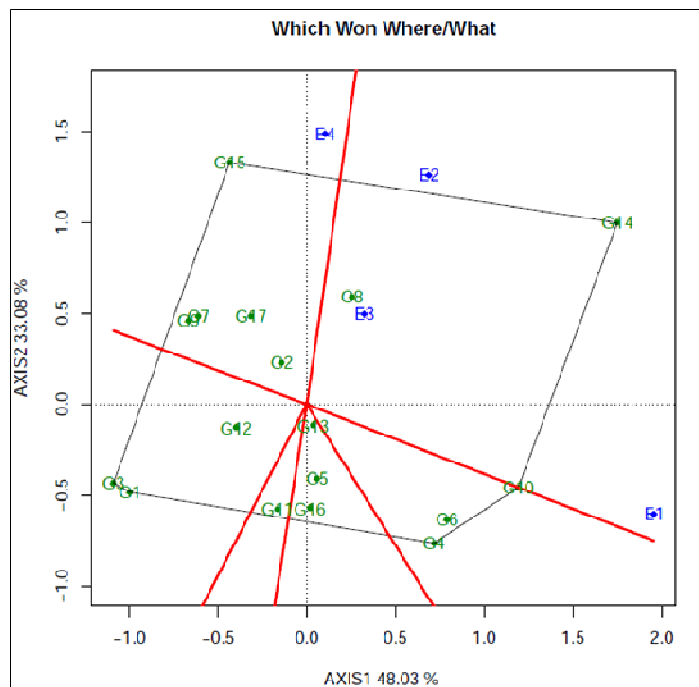


Fig. 4.6 (d) Which won where/what GGE Biplot 1 for root girth of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

4.1.7 Core girth (cm)

Both the locations L1 (Ludhiana) and L2 (KVK Langroya) as shown in table 4.2, the core girth of carrot was significantly better in L2 (1.63) which was statistically at par with L1 (1.23 cm). Date of sowings also had significant effect on core girth. D4 (First week of November) showed significantly higher core girth over D1 (First week of September), D3 (Second week of October) and D2 (Last week of September). The core girth differed significantly due to genotypes. It ranged from 1.05 to 1.68 cm. Genotype 14 (Carrot Nantes) showed the maximum (1.68 cm) core girth which was statistically at par with genotype 16 (Pusa Meghali) having 1.60 cm core girth and significantly better over all other genotypes.

4.1.8 Flesh Thickness

Flesh Thickness of the locations L1 (Ludhiana) and L2 (KVK Langroya) shown in table 4.2, the core girth of carrot was significantly better in L2 (1.63) which was statistically at par with L1 (1.23 cm). Date of sowings also had significant effect on core girth. D4 (First week of November) showed significantly higher core girth over D2 (Last week on September), D3 (Second week of October) and D1 (First week of September). The core girth differed significantly due to genotypes. It ranged from 1.05 to 1.68 cm. Genotype 14 (Carrot Nantes) showed the maximum (1.68 cm) core girth which was statistically at par with genotype 16 (Pusa Meghali) having 1.60 cm core girth and significantly better over all other genotypes.

4.1.9 Root Shoot ratio

Table 4.2 depicts that the locations L1 (Ludhiana) and L2 (KVK Langroya), the root shoot ratio of carrot was significantly better in L2 (3.24) as compared to L1 (2.52). Date of sowings also had significant effect on root shoot ratio. Fourth Date of sowing was significantly higher in root shoot ratio over other sowing dates. The root shoot ratio differed significantly due to genotypes. It ranged from 3.34 to 2.13. Genotype 17 (Arka Suraj) showed the maximum (3.34) root shoot ratio which was statistically at par with genotype 10 (P-35) with 3.28, genotype 8 (P-28) with 3.30, genotype 1 (P-3) with 3.20 root shoot ratio and significantly better over all other genotypes.

Tewatia and Dudi (1999) evaluated 26 genotypes of carrot and observed that root weight, shoot weight and root to shoot ratio were the most variable characters. Tewatia *et al* (2000b) found that HC-1 (1.80) had the maximum root to top ratio followed by Jind collection (1.50), HCER (1.30) and Pusa Kesar (1.20). Similarly, Bhatia *et al* (2002b) found maximum root in Desi red karnal (1.41) and HC-2 (1.40).

4.1.9 Days to Ist Root harvest

Table 4.2 explained that at location L1 (Ludhiana) and L2 (KVK Langroya), the total root yield of carrot was recorded which were significantly better in L1 (107.61) as compared to L2. Date of sowings also had significant effect on total root yield. D4 showed plants

significantly took less days and were better over D3, D2 and D1. Days to 1st root harvest differed significantly due to genotypes. Genotype G17 and genotype 6 showed the minimum (107.62) days to root harvest which was statistically at par with genotype 3, genotype 5, genotype 13 and genotype 16 and significantly better over all other genotypes.

4.1.10 Total root yield (kg/plot)

At both the locations L1 (Ludhiana) and L2 (KVK Langroya), the total root yield of carrot was recorded which were significantly better in L2 (25.31) as compared to L1 (22.37). Date of sowings also had significant effect on total root yield. D4 showed significantly higher total root yield which was significantly better over D3, D2 and D1. The total root yield differed significantly due to genotypes. It ranged from 21.45 to 25.96. Genotype G7 (P-23) showed the maximum (25.96) total root yield which was statistically at par with genotype 15 (24.82), genotype 14 (Carrot Nantes) with 26.93 kg/plot and significantly better over all other genotypes.

These existed a significantly interaction between sowing dates and genotypes. Nandal *et al* (2008) revealed that the maximum roots harvested in September with line sowing on ridges and minimum was recorded from the August sown crop.

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for total root yield was given in Figure 4.10 (a & b). At location 1 (PAU, Ludhiana), the genotypes P-29 (G9), PCO-6 (G13), P-3 (G1) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Early Nantes (G15) had maximum Total root yield exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-4 (G2) and P-5 (G3) was poor performers across the four plantings (four environments) due to minimum total root yield.

The GGE Biplot 1 performance of genotypes and environments for total root yield of location 2 is illustrated in Fig. 4.10 (b). The genotypes P-18 (G6) and PCO-6 (G13) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-17 (G5) and Pusa Meghali (G16) had maximum plant height exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype Carrot Early Nantes (G15) was poor performer across the four plantings (four environments) due to minimum Total root yield. The genotype Carrot Nantes(G12) had maximum Total root yield and was suitable for unfavorable environment (lower IPCA 1 value) and also had highest negative interaction with environment coupled with maximum total root yield that showed its moderate response to environmental changes.

Table 4.3 Effect of location, date of sowing and genotypes on total root yield (kg/plot), total root yield (q/acre), marketable root yield (kg/plot) and marketable root yield (q/acre)

		Total root yield (kg/plot)	Total root yield (q/acre)	Marketable root yield (kg/plot)	Marketable root yield (q/acre)
Locations	L1	22.37	165.73	21.30	157.84
	L2	25.31	187.47	24.05	178.20
	CD (5%)	0.13	1.02	0.16	1.23
Date of sowings	D1	15.16	112.34	14.30	105.97
	D2	20.31	150.46	19.51	144.58
	D3	28.89	214.03	27.46	203.41
	D4	30.99	229.57	29.44	218.13
	CD (5%)	0.19	1.44	0.23	1.75
Genotypes	G1	24.18	179.12	23.15	171.50
	G2	22.23	164.70	20.87	154.65
	G3	22.51	166.73	21.64	160.34
	G4	21.45	158.97	20.34	150.71
	G5	23.29	172.53	22.28	165.09
	G6	24.41	180.85	23.41	173.46
	G7	25.96	192.34	24.77	183.49
	G8	23.34	172.90	22.37	165.71
	G9	24.34	180.30	22.75	168.58
	G10	23.95	177.46	23.05	170.75
	G11	23.01	170.47	21.28	157.69
	G12	23.91	177.10	22.90	169.68
	G13	24.79	183.67	23.05	170.80
	G14	26.93	199.50	25.86	191.57
	G15	24.82	183.84	23.60	174.84
	G16	22.42	166.06	21.59	159.99
	G17	23.71	175.65	22.61	167.51
	CD(5%)	0.45	3.34	0.45	3.40
	Locations × Date of sowings	0.27	2.04	0.33	2.47
	Locations × Genotypes	0.63	4.73	0.64	4.81
Date of sowings × Genotypes	0.90	6.69	0.92	6.80	
Locations × Date of sowings × Genotypes	1.27	9.46	1.29	9.62	

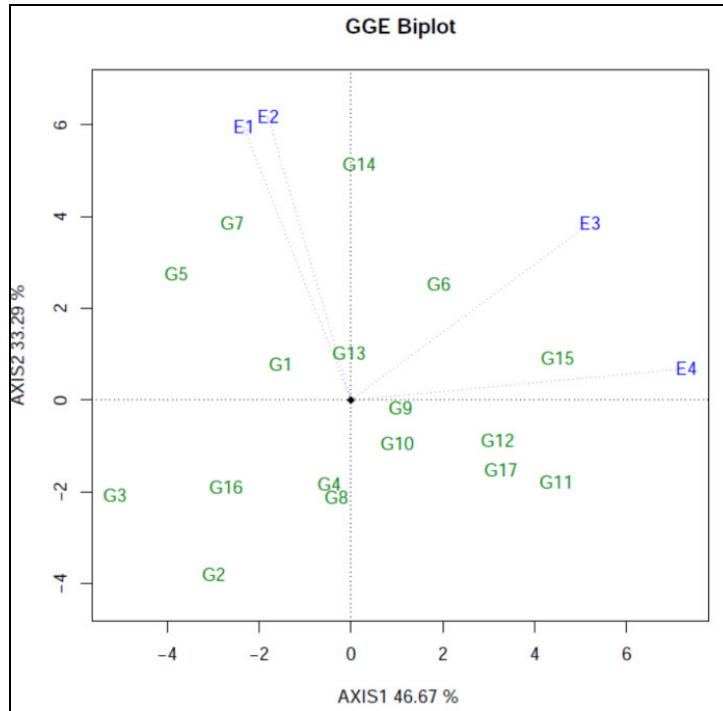


Fig. 4.7 (a) GGE Biplot 1 for total root yield (kg/plot) of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

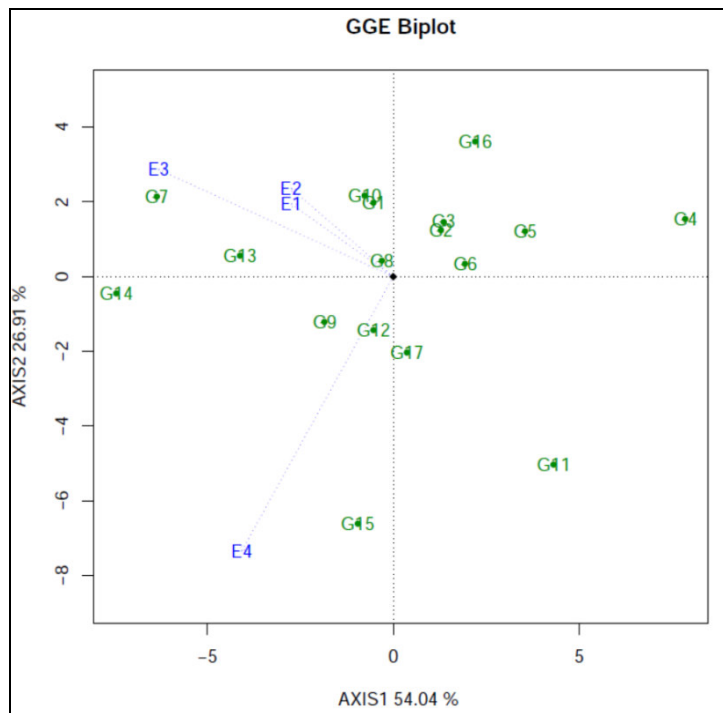


Fig. 4.7 (b) GGE Biplot 1 for total root yield (kg/plot) of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

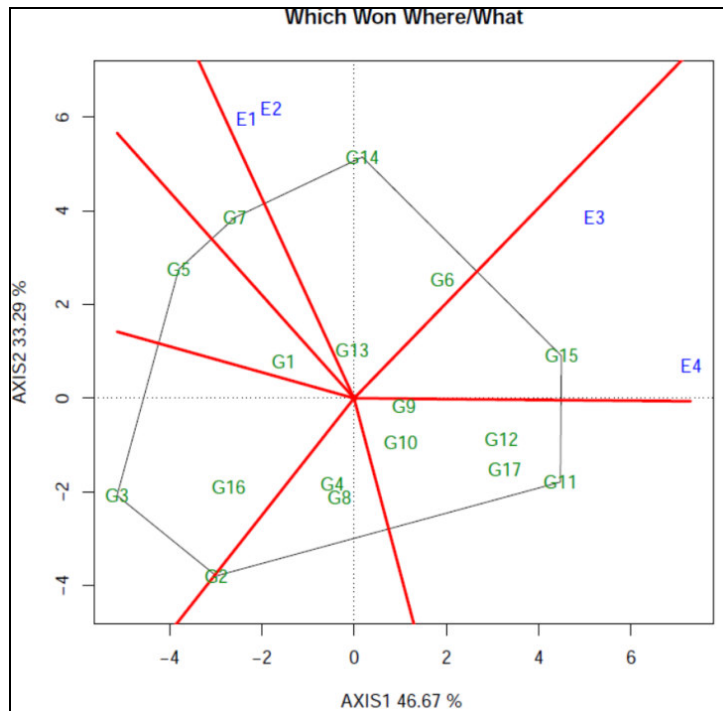


Fig. 4.7 (c) Which won where/what GGE Biplot 1 for total root yield (kg/plot) of carrot of 17 genotypes in 4 environments at location L1 (PAU, Ludhiana)

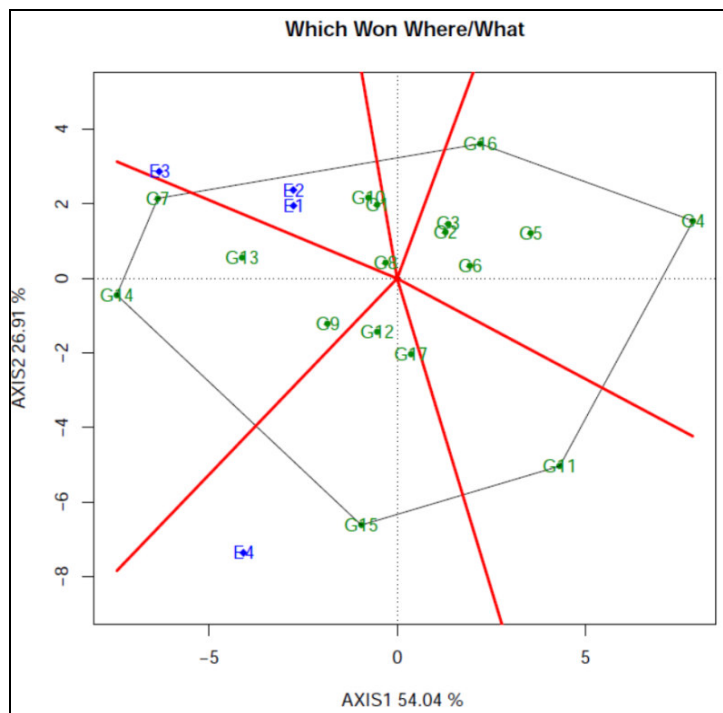


Fig. 4.7 (d) Which won where/what GGE Biplot 1 for total root yield (kg/plot) of carrot of 17 genotypes in 4 environments at location L2 (KVK, Langroya)

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.10 (c) of GGE Biplot. A polygon connecting the P-41 (G11), P-4 (G2), Carrot Nantes(G14), Carrot Early Nantes (G15) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E2, E4) included in one single environment and E₁ & E₃ lied in other mega environment while other four mega environments did not include any environment. The genotypes P-29 (G9) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

The stability of genotypes and environments (sowings), as well as specific G×E interaction at locations 2 (KVK, Langroya) is represented in Figure 4.10 (d) of GGE Biplot. A polygon connecting the G7, G14, G11, G4, G16 from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E2, E4) included in one single environment and E₁ & E₃ lied in different mega environments while other four mega environments did not include any environment. The genotypes P-28 (G8) and PCO-6 (G13) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.1.11 Total root yield (q/acre)

Total root yield (q/acre) was recorded at both the locations L1 (Ludhiana) and L2 (KVK Langroya), the total root yield (q/acre) of carrot was significantly better in L2 (187.47) as compared to L1 (165.73). Date of sowings also had significant effect on total root yield (q/acre). D4 showed significantly higher total root yield (q/acre) as compared to D1, D2 and D3. The total root yield (q/acre) differed significantly due to genotypes. It ranged from 158.97 to 199.50. Genotype 14 (Carrot Nantes) showed the maximum (199.50), genotype 7 (P-23) and genotype 15 (Carrot Early Nantes) total root yield and significantly better over all other genotypes.

4.1.12 Marketable root yield (kg/plot)

Marketable root yield (kg/plot) was recorded at both the locations L1 (Ludhiana) and L2 (KVK Langroya). Marketable root yield (kg/plot) of carrot was significantly better in L2 (24.05) as compared to L1 (21.30). Date of sowings also had significant effect on total root yield (q/acre). D4 showed significantly higher Marketable root yield (kg/plot) as compared to D1, D2 and D3. The differed significantly due to genotypes. It ranged from 20.34 to 25.86.

Genotype 14 (Carrot Nantes) showed the maximum (25.86), genotype 7 (P-23) marketable root yield and significantly better over all other genotypes.

Panda *et al* (1994) revealed that the maximum percentage of marketable roots (94.24%) was recorded in Nantes Scarlet and minimum marketable roots (68.31%) were recorded in Golden red. Studies of Bhatia *et al* (2002 b) showed that the weight of marketable roots per plot was recorded to be highest in HC-153P (3.30 kg) followed by HCER-J (3.26 kg) and HC-37(3.10 kg) while it was lowest in HC-199.

4.1.13 Marketable root yield (q/acre)

Marketable root yield (q/acre) was recorded at both the locations L1 (Ludhiana) and L2 (KVK Langroya). Marketable root yield (q/acre) of carrot was significantly better in L2 (178.20) as compared to L1 (157.84). Date of sowings also had significant effect on total root yield (q/acre). D4 showed significantly higher Marketable root yield (q/acre) as compared to D1, D2 and D3. They differed significantly due to genotypes. It ranged from 191.57 to 150.71. Genotype 14 (Carrot Nantes) showed the maximum (191.57) marketable root yield and significantly better over all other genotypes.

4.1.14 Root forking

Root forking is a disorder which reduces the market value of the roots. The pooled data of both the locations depicted no significant differences amongst genotypes with respect to root forking (%) as shown in Table 4.4. Root forking categorized all the genotypes into low class (0 to 20% forking). Dhillon (2015) found all the 3 categories of forking in 38 carrot genotypes.

4.1.15 Root shape

Root shape is an important character which increases the market value of the carrot root. Temperature plays an important role for the development of root shape eg. longer and cylindrical roots are obtained at 13 °C to 20 °C while the temperature above 20 °C results in shorter and thicker roots. European carrot genotypes do not show any variability within genotypes (Table 4.4). According to root shape, all the European carrot genotypes are of cylindrical shape except genotype 17 (Arka Suraj) which had conical shape.

4.1.16 Root color

Root color is an important character for physical appearance of roots because the carotenoid and anthocyanin content in carrot are associated with the color of roots (Nicolle *et al* 2004). Present set of genotypes were categorized as possessing orange, dark orange and light orange coloured European genotypes (Table 4.4). Thirteen genotypes possessed dark orange root color and the rest four genotypes contained light orange coloured root.

4.1.17 Core color

Core color of carrot is an important trait from processing point of view as thin and self-colored core is preferred for commercial production of carrots (Kumar *et al* 2011). The

self-color core and light yellow colored core were present in many genotypes (Table 4.4). Most of the dark orange coloured carrot genotypes were self cored (11 genotypes) or have light orange core (2 genotypes). Light orange coloured roots showed light yellow coloured core (4 genotypes).

Table 4.4: Root shape, root colour, core colour and root forking of European carrot genotypes of both locations (L1 & L2)

Genotype	Root Shape	Root colour	Core colour	Root Forking
P-3 (G1)	Cylindrical	Dark Orange	Self Core	Low
P-4 (G2)	Cylindrical	Dark Orange	Light Orange	Low
P-5 (G3)	Cylindrical	Dark Orange	Self Core	Low
P-16 (G4)	Cylindrical	Dark Orange	Self Core	Low
P-17 (G5)	Cylindrical	Dark Orange	Light Orange	Low
P-18 (G6)	Cylindrical	Light Orange	Light Yellow	Low
P-23 (G7)	Cylindrical	Dark Orange	Self Core	Low
P-28 (G8)	Cylindrical	Light Orange	Light Yellow	Low
P-29 (G9)	Cylindrical	Dark Orange	Self Core	Low
P-35 (G10)	Cylindrical	Dark Orange	Self Core	Low
P-41 (G11)	Cylindrical	Light Orange	Light Yellow	Low
PCO-4 (G12)	Cylindrical	Dark Orange	Light Yellow	Low
PCO-6 (G13)	Cylindrical	Light Orange	Self Core	Low
Carrot Nantes(G14)	Cylindrical	Dark Orange	Self Core	Low
Carrot Early Nantes (G15)	Cylindrical	Dark Orange	Self Core	Low
Pusa Meghali (G16)	Cylindrical	Dark Orange	Self Core	Low
Arka Suraj (G17)	Tapering	Dark Orange	Self Core	Low

4.2 Biochemical characterization of carrot genotypes

4.2.1 Total soluble solids

While comparing both the locations for TSS of carrot i.e. L1 (Ludhiana) and L2 (KVK Langroya), the total soluble solids of carrot was significantly higher in L2 (8.33⁰B) as compared to L1 (7.13⁰B). Date of sowings also had significant effect on TSS of carrot. D4 (First week on November) showed significantly higher TSS (8.33) which was statistically at par with D3 (Second week of October) and significantly better over D2 (Last week of September) and D1 (First week of September). The TSS of carrot differed significantly due to genotypes. It ranged from 7.25 to 8.58 ⁰B. Genotype 10 (P-35) showed the maximum TSS which was statistically at par with genotype 3 (8.56 ⁰B), genotype 15 (8.54 ⁰B) and significantly higher over all other genotypes. Singh *et al* (2004) observed large variation for

total soluble solids and it varied from 3.83%-8.04% when grown at different dates of sowing.

GGE Biplot 1

Based on the GGE Biplot 1 performance of genotypes and environments for total soluble solids was given in Figure 4.8(a & b). At location 1 (PAU, Ludhiana), the genotypes Arka suraj (G17), PCO-6 (G13), P-28 (G8), P-3 (G1) and Carrot F1 (G14) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Nantes (G12) had maximum Total soluble solids exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-17 (G5), PCO-4 (G10) and P-5 (G3) was poor performers across the four plantings (four environments) due to minimum total soluble solids (TSS).

The GGE Biplot 1 performance of genotypes and environments for total soluble of location 2 is illustrated in Fig. 4.8 (b). The genotypes P-18 (G6), Arka Suraj (G17), P-16 (G4) and P-28 (G7) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Nantes (G12) and PCO-4 (G10) had maximum plant height exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-17 (G5) was poor performer across the four plantings (four environments) due to minimum TSS. The genotype Carrot Nantes (G12) had maximum plant height and was suitable for unfavorable environment (lower IPCA 1 value) and also had highest negative interaction with environment coupled with maximum total soluble solids that showed its moderate response to environmental changes.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.8 (c) of GGE Biplot. A polygon connecting the P-3 (G1), P-17 (G5), PCO-4 (G10), Carrot Nantes(G12) furthest (had highest vectors in their particular direction)from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₂, E₄) included in one single environment and E₁ & E₃ lied in other mega environment while other four mega environments did not include any environment. The genotypes PCO-6 (G13) and P-28 (G8) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.14 (d) of GGE Biplot. A polygon connecting the P-17 (G5), P-35 (G10), P-29 (G9), PCO-4 (G12), P-5 (G3), P-35

Table 4.5: Effect of locations, date of sowings and genotypes on total soluble solids, dry matter, sugar content, carotene content and juice yield per kg of carrot.

		Total Soluble Solids (°Brix)	Dry matter (%)	Sugar content (%)	Carotene Content (mg/100g)	Juice yield (ml/kg)
Locations	L1	7.88	11.04	7.81	7.70	485.14
	L2	8.13	16.19	7.98	7.80	487.84
	CD (5%)	0.66	NS	0.46	0.022	NS
Date of sowings	D1	7.73	20.70	7.54	7.19	448.49
	D2	7.90	10.91	7.77	7.58	487.97
	D3	8.06	11.42	8.11	8.18	506.84
	D4	8.33	11.43	8.15	8.04	502.67
	CD (5%)	0.94	NS	0.65	0.031	4.54
Genotypes	G1	7.39	10.09	7.88	7.50	462.29
	G2	8.15	10.99	7.85	6.87	442.00
	G3	8.56	11.39	7.79	7.45	463.08
	G4	7.76	10.05	8.04	9.42	481.29
	G5	7.25	11.42	7.72	7.91	424.62
	G6	7.90	12.88	7.84	7.94	468.25
	G7	7.76	10.71	7.53	7.84	474.29
	G8	7.94	11.06	7.85	7.51	492.08
	G9	7.73	10.47	7.89	7.61	436.12
	G10	8.58	10.17	7.93	8.44	549.75
	G11	8.09	12.75	8.03	8.16	410.70
	G12	8.52	10.35	8.08	7.40	534.50
	G13	7.92	9.83	7.82	7.60	549.45
	G14	7.50	10.44	7.88	7.58	542.58
	G15	8.54	10.45	8.04	7.00	475.25
	G16	8.30	11.92	8.05	7.56	510.79
	G17	8.24	11.49	7.97	7.92	552.75
	CD(5%)	0.10	NS	0.78	0.059	8.08
	Locations × Date of sowings	NS	NS	0.92	0.044	NS
	Locations × Genotypes	NS	NS	NS	NS	NS
Date of sowings × Genotypes	0.20	NS	0.15	0.011	16.17	
Locations × Date of sowings × Genotypes	NS	NS	NS	NS	NS	

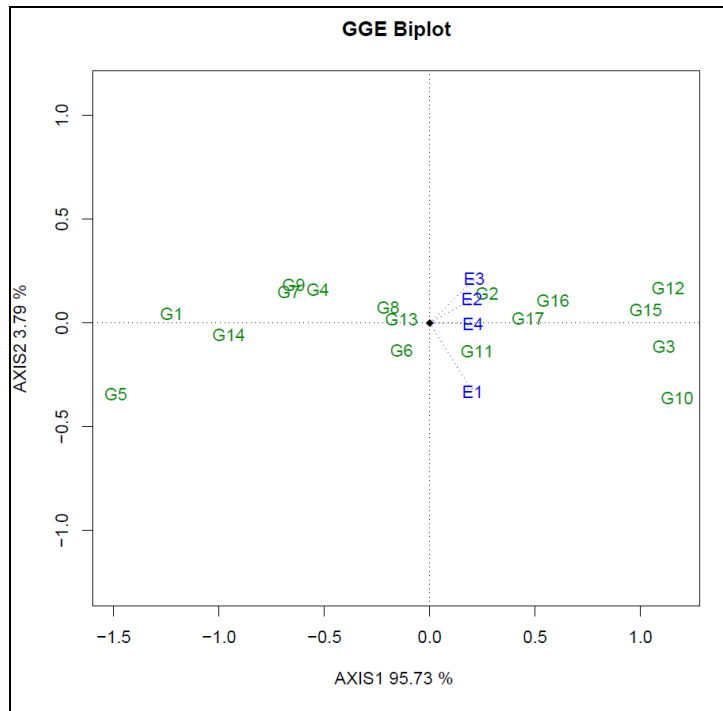


Fig 4.8 (a) GGE Biplot for total soluble solids of carrot showing the interaction of 17 genotypes in 4 environments of location L1

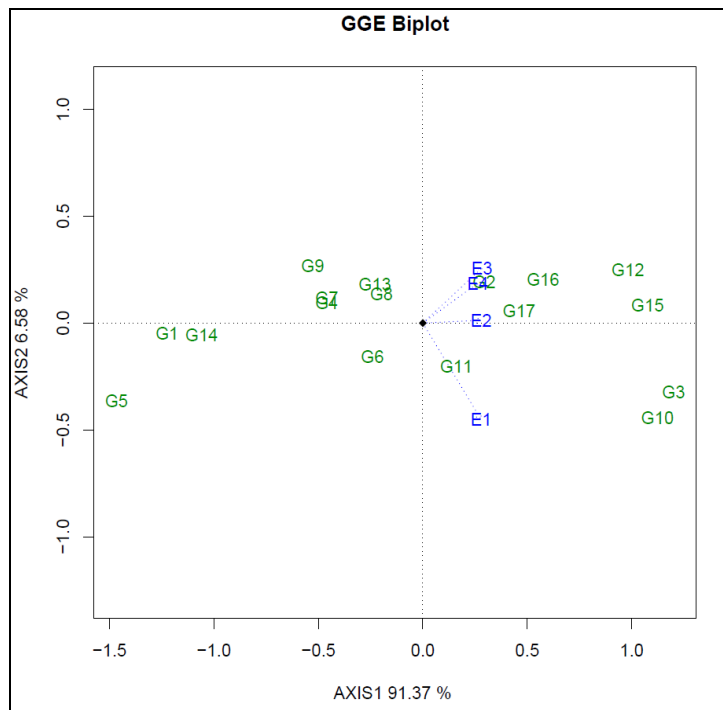


Fig 4.8 (b) GGE Biplot for total soluble solids of carrot showing the interaction of 17 genotypes in 4 environments of location L2

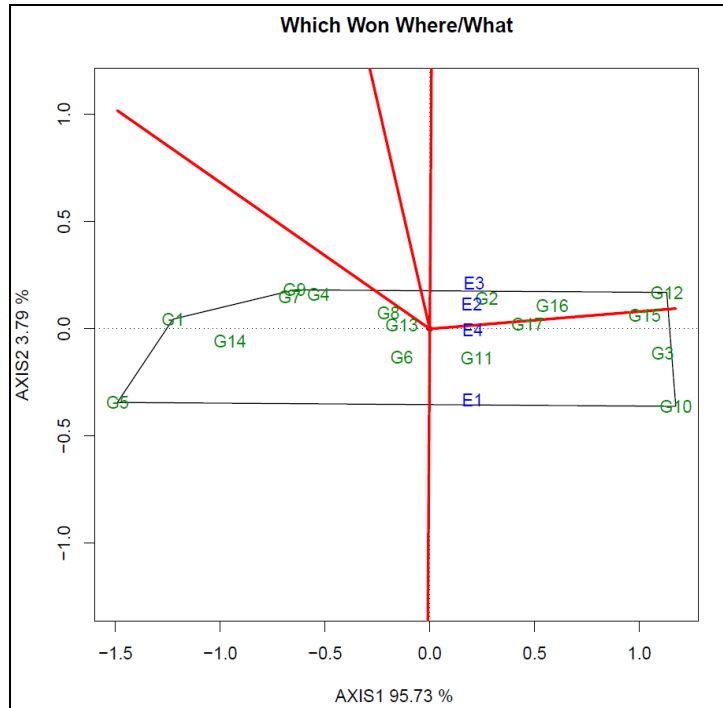


Fig 4.8 (c) Which Won Where GGE Biplot for total soluble solids of carrot showing the interaction of 17 genotypes in 4 environments of location L1

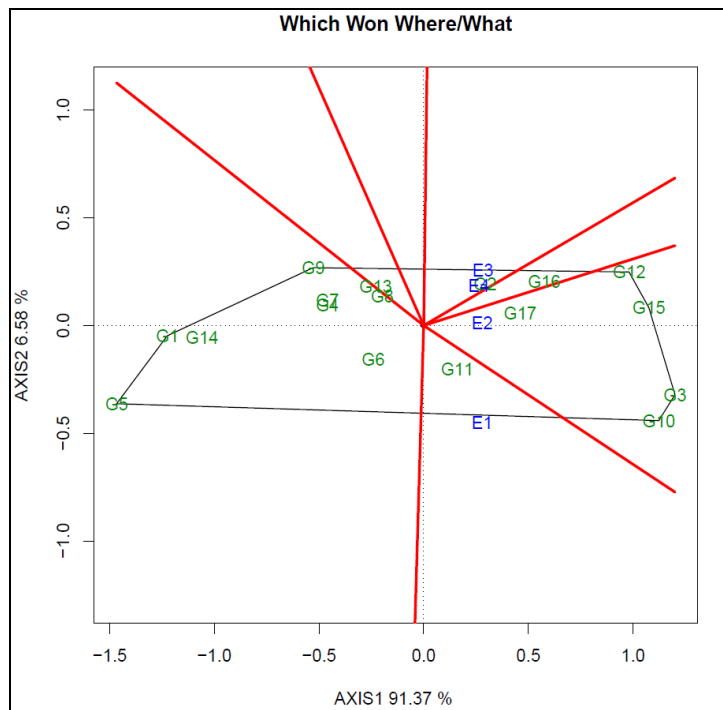


Fig 4.8 (d) Which Won Where GGE Biplot for total soluble solids of carrot showing the interaction of 17 genotypes in 4 environments of location L2

(G10) and Carrot Nantes(G14) furthest (had highest vectors in their particular direction)from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E₂, E₄) included in one single environment and E₁ & E₃ lied in different mega environments while other four mega environments did not include any environment. The genotypes P-28 (G8) and PCO-6 (G13) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.2.2 Dry matter (%)

While comparing different locations for dry matter of carrot it was observed that the dry matter of carrot for location L2 i.e. KVK Langroya (16.19 %) was significantly higher than L1 i.e. Ludhiana (11.04%).Date of sowings also had significant effect on dry matter of carrot. D1 (First week of September) showed significantly higher dry matter (8.33) than D4 (First week on November), D3 (Second week of October) and D2 (Last week of September) which was statistically at par with each other. The dry matter of carrot differed significantly due to genotypes. It ranged from 9.83 to 12.88 per cent. Genotype 4 showed the maximum dry matter followed by genotype 6 (12.88%) which was statistically at par with genotype 11 (12.75%).

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for dry matter was given in Figure 4.9 (a). At location 1 (PAU, Ludhiana), the genotypes Carrot Nantes (G14), Carrot Early Nantes (G15), Pusa Meghali (G16) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-41 (G11) had maximum dry matter exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-18 (G6) and PCO-6 (G13) was poor performers across the four plantings (four environments).

The GGE Biplot 1 performance of genotypes and environments for dry matter of location 2 is illustrated in Fig. 4.9 (b). The genotypes Pusa Meghali (G16), Carrot Nantes (G14), Carrot Early Nantes (G15) and P-29 (G9) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Nantes (G12) and PCO-4 (G10) had maximum dry weight exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-18 (G6) was poor performer across the four plantings (four environments) due to minimum dry matter.

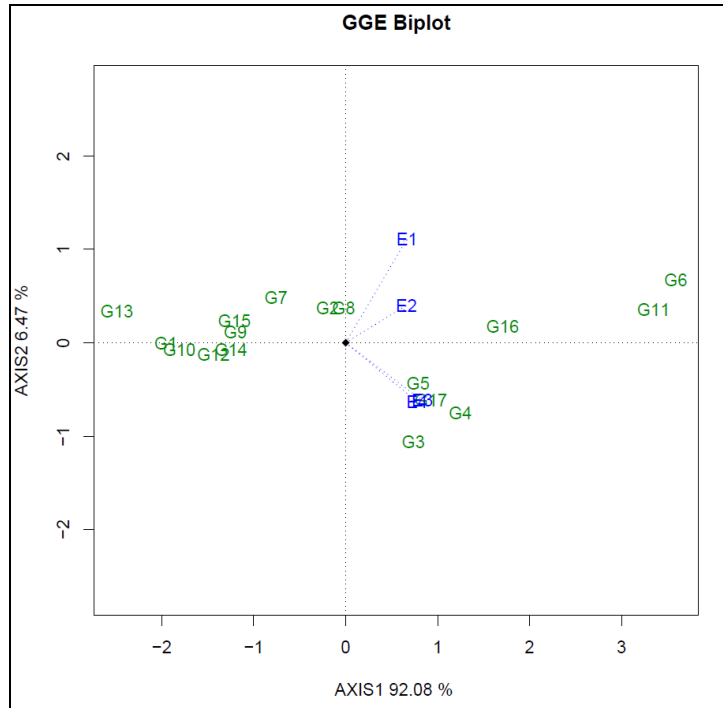


Fig 4.9 (a) GGE Biplot 1 for dry matter of carrot showing the interaction of 17 genotypes in 4 environments of location L1

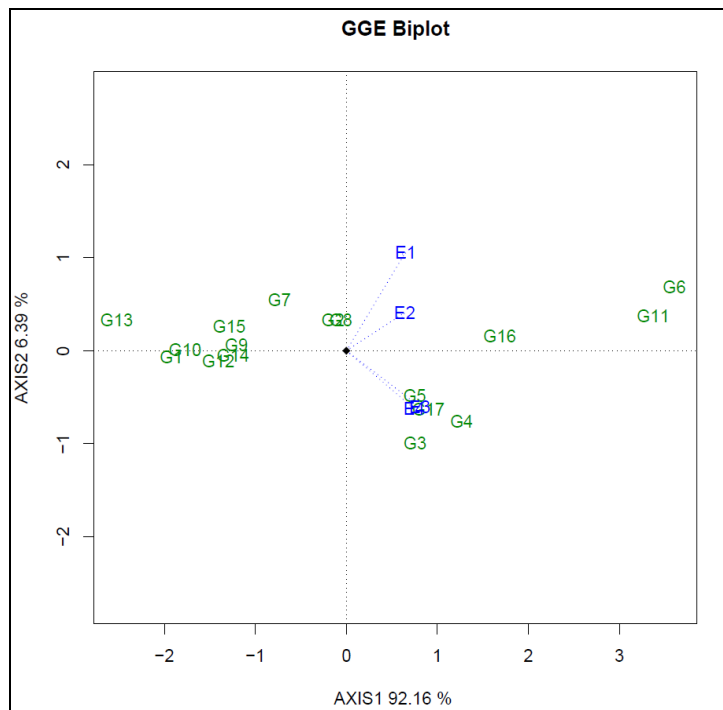


Fig 4.9 (b) GGE Biplot 1 for dry matter of carrot showing the interaction of 17 genotypes in 4 environments of location L2

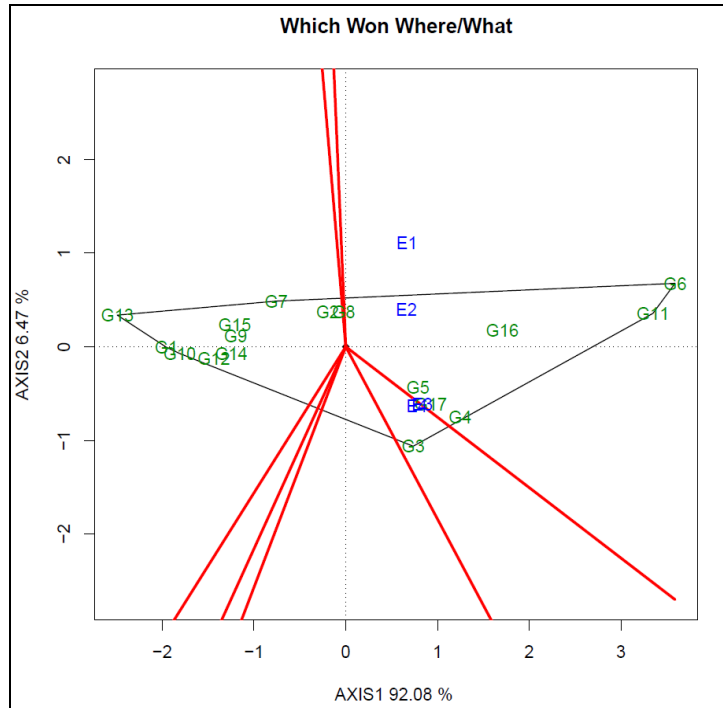


Fig 4.9 (c) Which Won Where GGE Biplot for dry matter of carrot showing the interaction of 17 genotypes in 4 environments of location L1

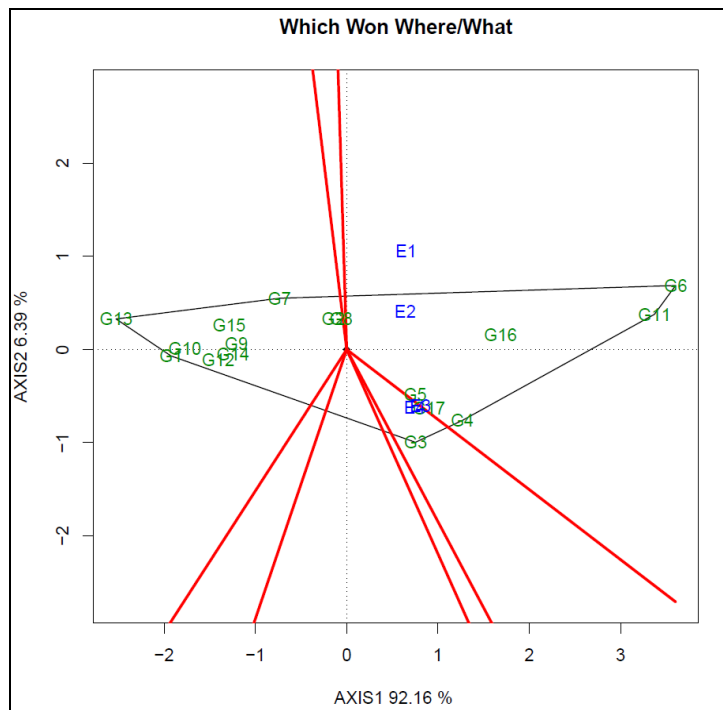


Fig 4.9 (d) Which Won Where GGE Biplot 1 for dry matter of carrot showing the interaction of 17 genotypes in 4 environments of location L2

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.9 (c) of GGE Biplot. A polygon connecting the P-5 (G3), P-18 (G6), P-23 (G7), Carrot Early Nantes (G13) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E3, E₄) included in one single environment and E₁ & E₂ lied in other mega environment while other four mega environments did not include any environment. The genotypes P-4 (G2) and P-28 (G8) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction is represented in Figure 4.9 (d) of GGE Biplot. A polygon connecting the P-17 (G5), P-35 (G10), P-29 (G9), PCO-4 (G12), P-5 (G3), P-35 (G10) and Carrot Nantes (G14) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E2, E₄) included in one single environment and E₁ & E₃ lied in different mega environments while other four mega environments did not include any environment. The genotypes P-28 (G8) and PCO-6 (G13) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.2.3 Sugar content

The sugar content of carrot for both the locations was statistically at par with each other. D4 (First week on November) showed significantly higher sugar content which was statistically at par with D3 (Second week of October) and significantly better over D2 (Last week of September) and D1 (First week of September). The sugar content differed significantly due to genotypes. It ranged from 7.53 to 8.08 Genotype 12 showed the maximum sugar content which was statistically at par with genotype 16 (8.05) and significantly better over all other genotypes. According to Yadav *et al* (2009), the total sugar content ranged from 7.0 to 7.8%, while Teli *et al* (2017) studied the range of total sugar content from 2.20 to 4.30 % in 30 carrot genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for sugar content was given in Figure 4.10 (a). At location 1 (PAU, Ludhiana), the genotypes Carrot F1 (G14),

Carrot Early Nantes (G15), P-5 (G3) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-29 (G9) had maximum sugar content exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype and P-16 (G4) was poor performers across the four plantings (four environments) .

Fig. 4.10 (b) showed the GGE Biplot 1 performance of 17 genotypes and environments for sugar content of location 2. The genotypes PCO-4 (G12), Carrot F1 (G14) and Carrot Early Nantes (G15) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-29 (G9) and PCO-4 (G10) had maximum sugar content exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-16 (G4) was poor performer across the four plantings (four environments) due to minimum sugar content.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.10 (c) of GGE Biplot. A polygon connecting the P-16 (G4), P-4 (G2), P-23 (G7), P-29 (G9) and P-28 (G8) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E2, E4) included in one single environment and E₁ & E₃ lied in other mega environment while other four mega environments did not include any environment. The genotypes PCO-4 (G12) and Carrot Nantes (G14) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction is represented in Figure 4.10 (d) of GGE Biplot. A polygon connecting the P-23 (G7), P-16 (G4), P-29 (G9), P-4 (G2) followed by Carrot Early Nantes (G15) furthest (had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The environments (E2, E4) included in one single environment and E₁ & E₃ lied in different mega environments while other four mega environments did not include any environment. The genotypes Carrot Nantes(G14) and P-18 (G6) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

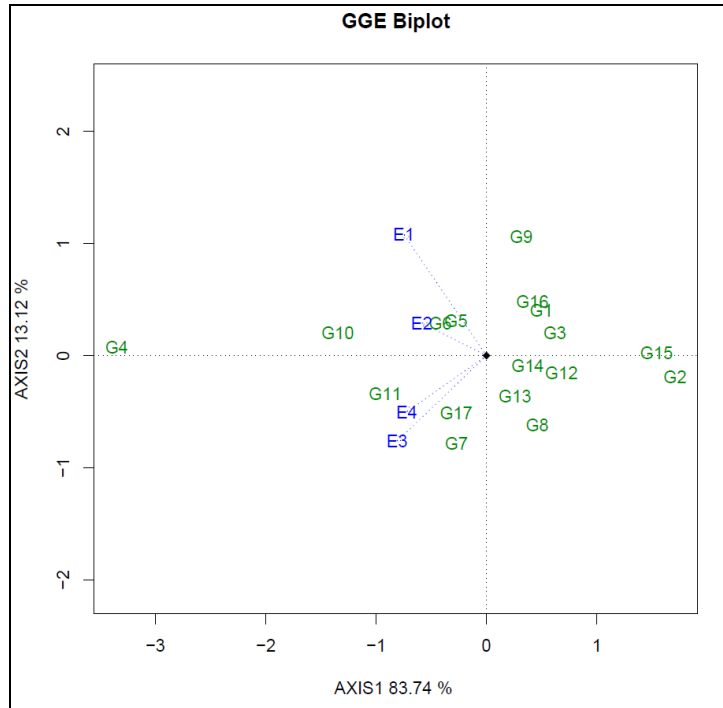


Fig 4.10 (b) GGE Biplot 1 for sugar content of carrot showing the interaction of 17 genotypes in 4 environments of location L1

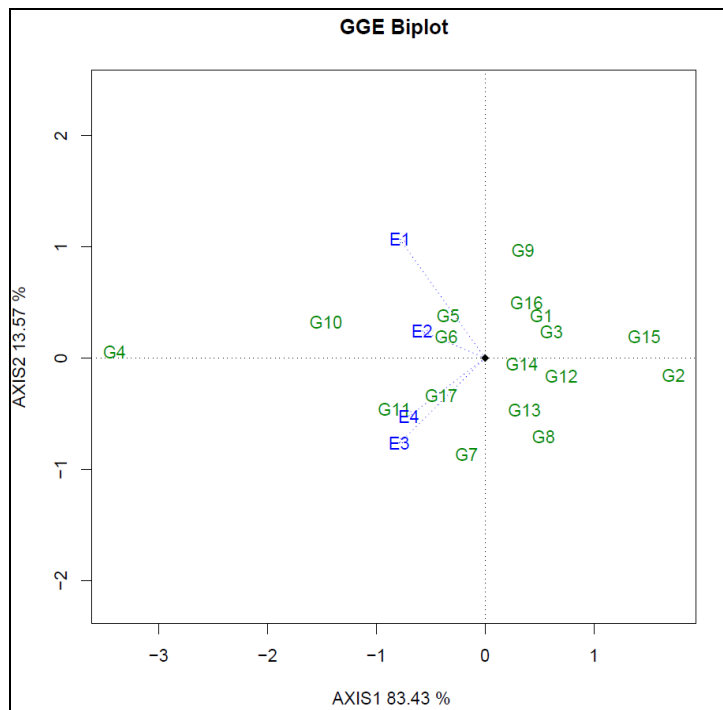


Fig 4.10 (b) GGE Biplot 1 for sugar content of carrot showing the interaction of 17 genotypes in 4 environments of location L2

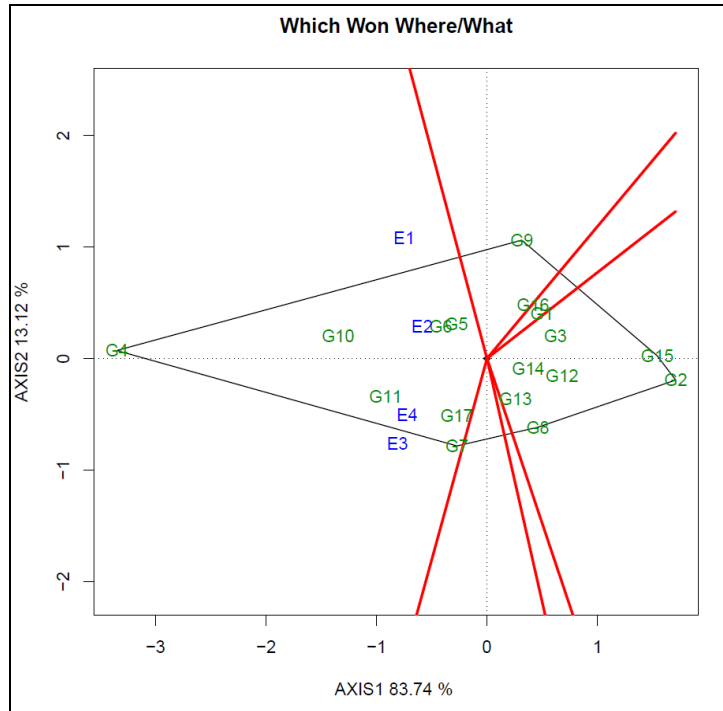


Fig 4.10 (c) What Won Where GGE Biplot for sugar content of carrot showing the interaction of 17 genotypes in 4 environments of location L1

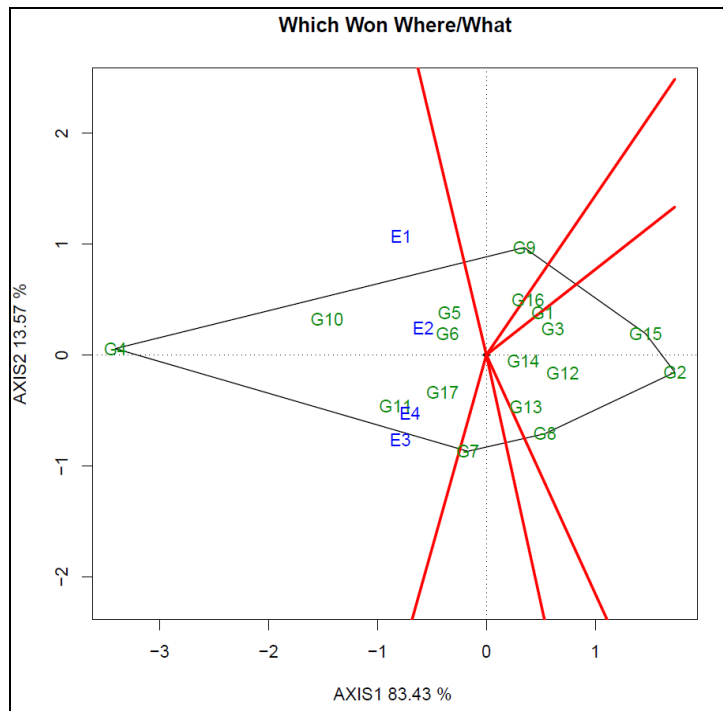


Fig 4.10 (d) What Won Where GGE Biplot for sugar content of carrot showing the interaction of 17 genotypes in 4 environments of location L2

4.2.4 β -Carotene content

By comparing both the locations for carotene content of carrot i.e. L1 (Ludhiana) and L2 (KVK Langroya) was statistically at par with each other. Date of sowings also had significant effect on carotene content of carrot. D3 (Second week of October) showed significantly higher carotene content (8.18) which was statistically at par with D4 (First week on November) i.e. 8.04 and significantly better over D2 (Last week of September) and D1 (First week of September). The carotene content of carrot for different genotypes ranged from 6.87 to 9.42. Genotype 4 showed the maximum carotene content followed by genotype 10 which was statistically at par with genotype 11.

Fikselova *et al* (2010) studied the influence of area, variety, year and storage on β -carotene content and dry matter content of selected carrot varieties. Carrot roots of four varieties were examined during two years period (2002-2003), cultivated under different climatic and soil conditions in three areas of Slovakia – Nitra, Komar-no and Prusy. Carrot varieties like Florida F1, Nevis F1 showed the greatest mean content of carotene in Nitra area in year 2003. Irrigation showed negative influence on carotene content. The highest content of carotene was in variety Florida F1 (26.3 mg/100g).

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for carotene content was given in Figure 4.11 (a & b). At location 1 (PAU, Ludhiana), the genotypes P-41 (G11), P-28 (G8), Carrot Early Nantes (G15) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Pusa Meghali (G16) had maximum carotene content exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype and P-23 (G7) was poor performers across the four plantings (four environments).

Fig. 4.11 (b) showed the GGE Biplot 1 performance of 17 genotypes and environments for carotene content of location 2. The genotypes PCO-4 (G12), P-16 (G4) and Carrot Early Nantes (G15), P-5 (G3) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Arka Suraj (G17) and Pusa Meghali (G16) had maximum carotene content exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-23 (G7) was poor performer across the four plantings (four environments) due to minimum carotene content.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.11 (c) of GGE Biplot. P-23 (G7), P-18 (G6), P-3 (G1), Carrot Nantes(G14), Carrot Early Nantes (G15), PCO-4 (G12) and Pusa Meghali (G16) connects the polygon and had highest vectors in their particular direction

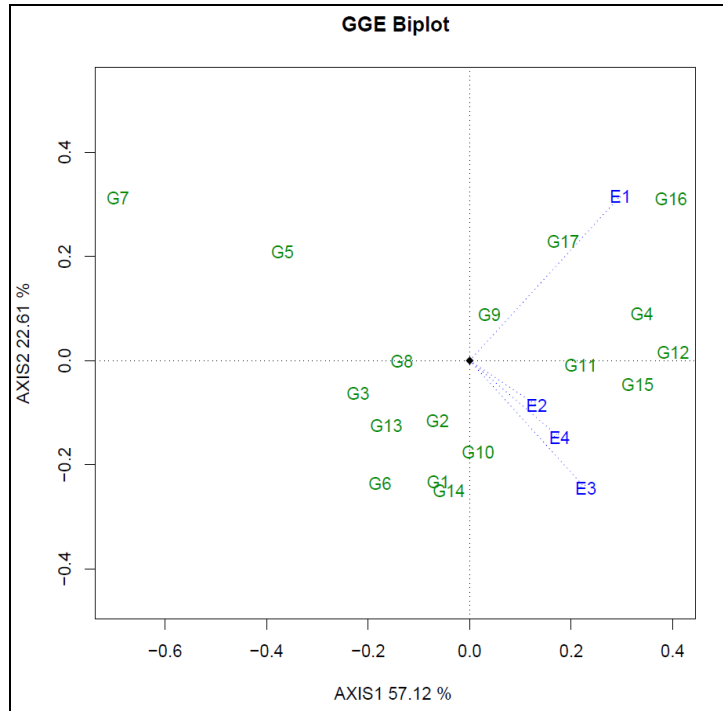


Fig 4.11 (a) What Won Where GGE Biplot for carotene content of carrot showing the interaction of 17 genotypes in 4 environments of location L1

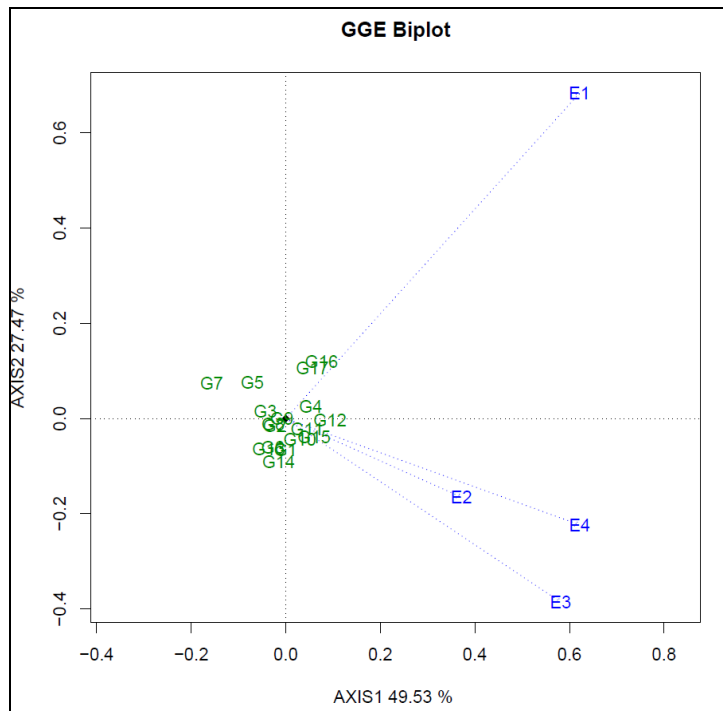


Fig 4.11 (b) What Won Where GGE Biplot for carotene content of carrot showing the interaction of 17 genotypes in 4 environments of location L2

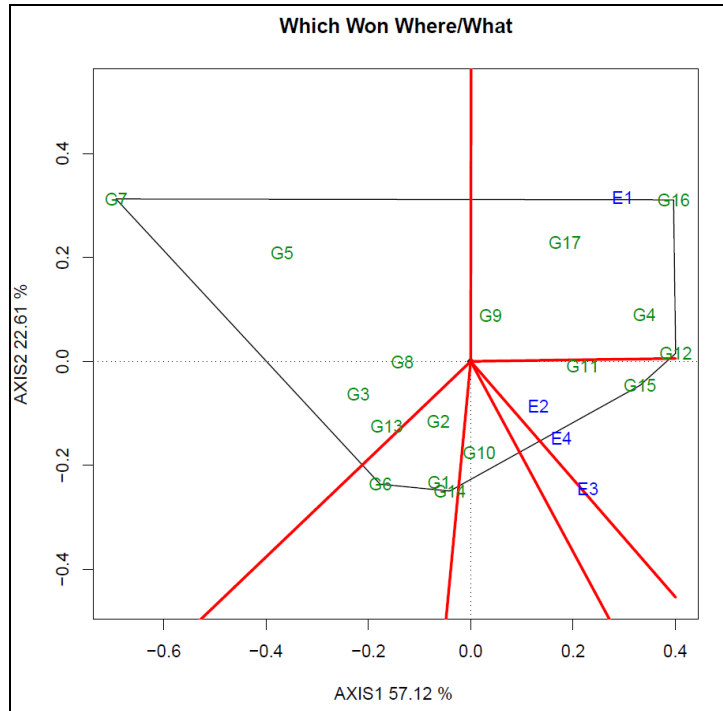


Fig 4.11 (c) What Won Where GGE Biplot for carotene content of carrot showing the interaction of 17 genotypes in 4 environments of location L1

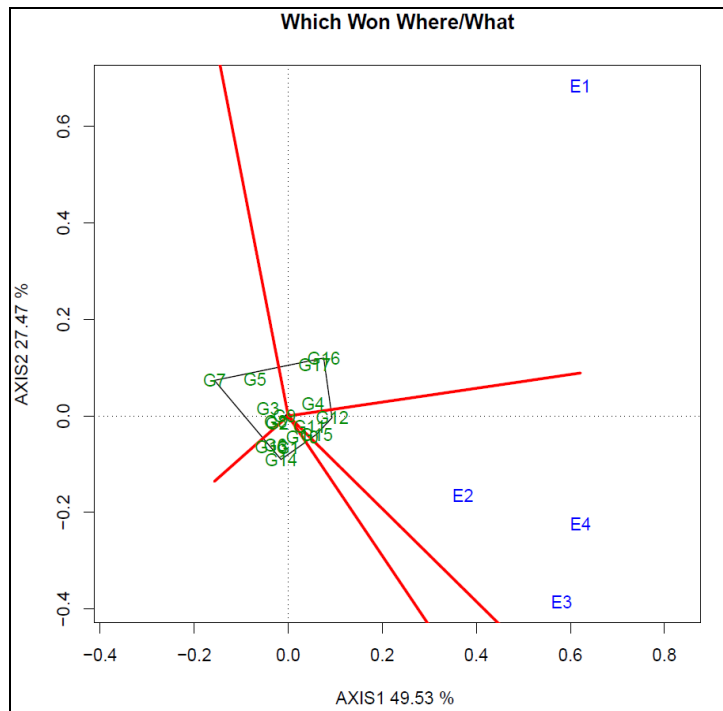


Fig 4.11 (d) What Won Where GGE Biplot for carotene content of carrot showing the interaction of 17 genotypes in 4 environments of location L2

from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-28 (G8) and P-4 (G2) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.11 (d) of GGE Biplot. The genotypes G7, G16, G12, G14 results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-5 (G3), P-16 (G4) and P-18 (G6) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.2.5 Juice yield

Juice yield was recorded from location L1 (Ludhiana) and L2 (KVK Langroya), the juice yield of carrot of both locations was statistically at par with each other. Date of sowings also had significant effect on plant height. D3 (Second week of October) showed significantly higher plant height which was statistically at par with D4 (First week on November) and significantly better over D2 (Last week of September) and D1 (First week of September). The juice yield differed significantly due to genotypes. It ranged from 410.70 to 552.75. Genotype 17 showed the maximum juice yield which was significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for juice yield content was given in Figure 4.12 (a & b). At location 1 (PAU, Ludhiana), the genotypes PCO-4 (G12), Carrot Early Nantes (G15), P-18 (G6) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-35 (G10), PCO-6 (G13), Carrot Nantes(G14), Arka Suraj (G17) had maximum juice yield exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype and P-41 (G11) was poor performers across the four plantings (four environments).

Fig. 4.12 (b) showed the GGE Biplot 1 performance of 17 genotypes and environments for juice yield of location 2. The genotypes P-18 (G6), P-3 (G1) and Carrot Early Nantes (G15) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Arka Suraj (G17) and PCO-4 (G10) had maximum juice yield exhibiting adaptation to all four

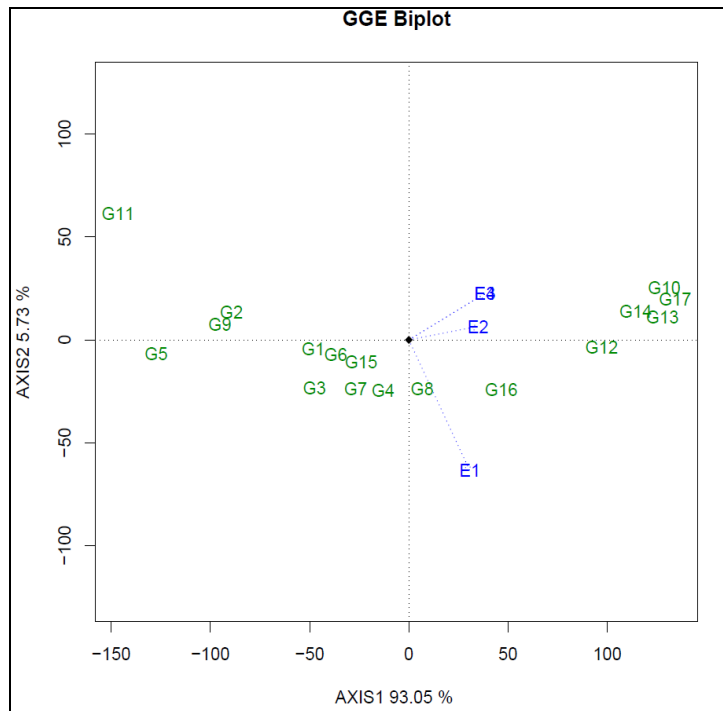


Fig 4.12 (a) GGE Biplot 1 for juice yield of carrot showing the interaction of 17 genotypes in 4 environments of location L1

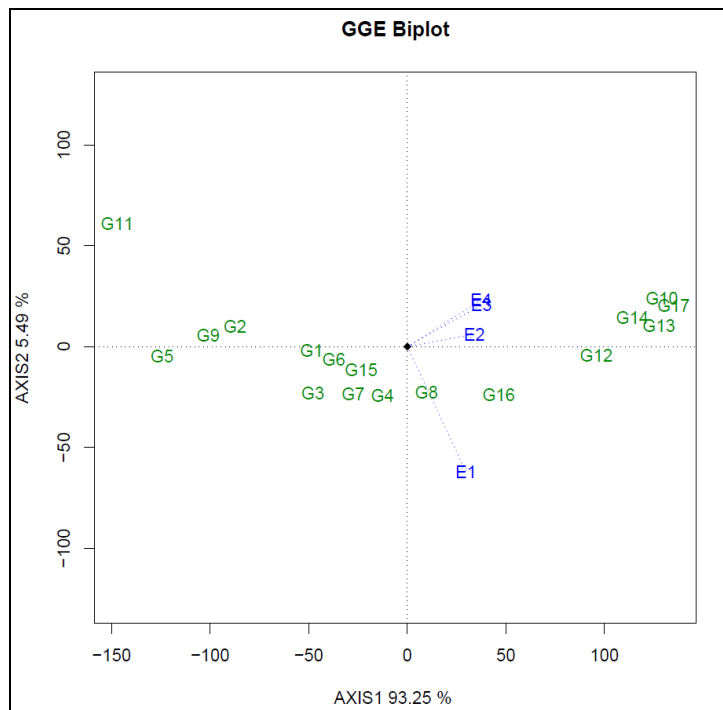


Fig 4.12 (b) GGE Biplot 1 for juice yield of carrot showing the interaction of 17 genotypes in 4 environments of location L2.

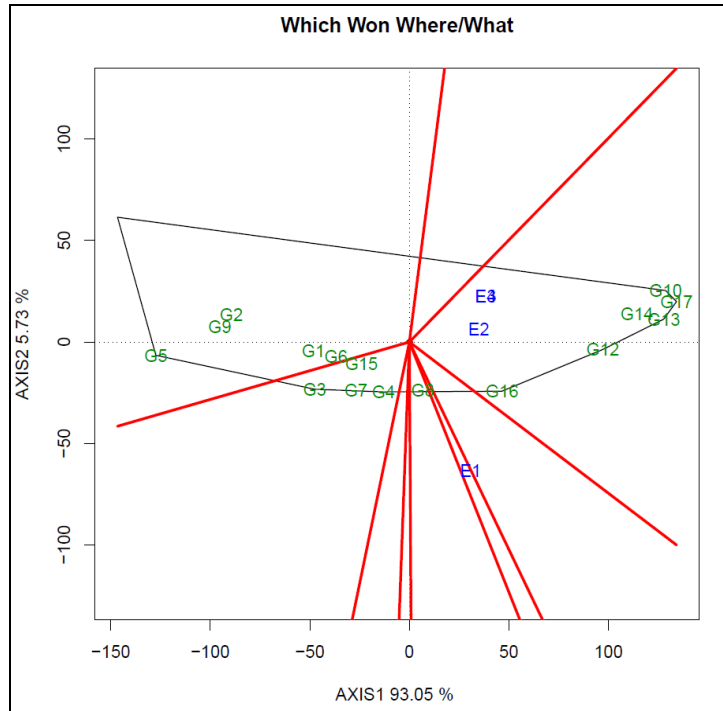


Fig 4.12 (c) What Won Where GGE Biplot for juice yield of carrot showing the interaction of 17 genotypes in 4 environments of location L1

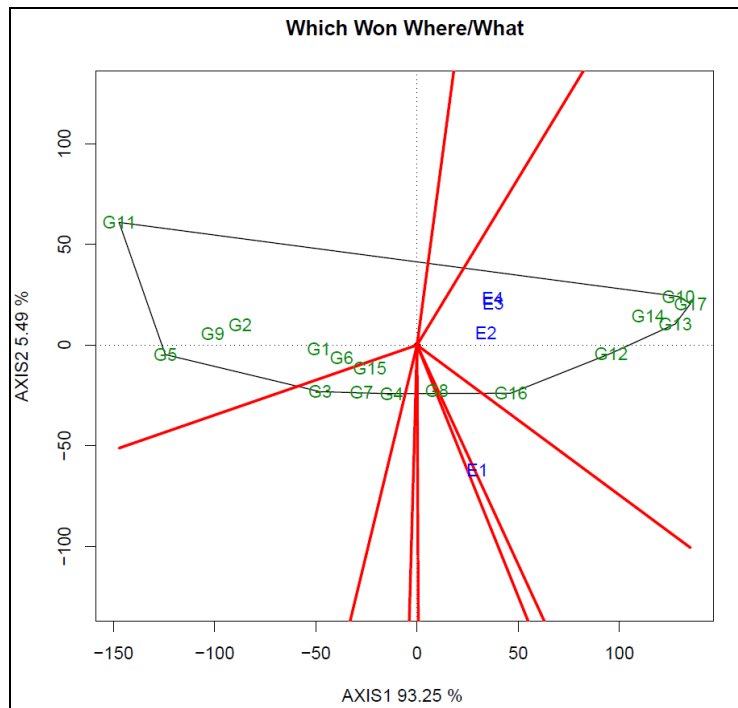


Fig 4.12 (d) What Won Where GGE Biplot for juice yield of carrot showing the interaction of 17 genotypes in 4 environments of location L2
environments and therefore categorized as generalists. The genotype P-41 (G11) was poor

performer across the four plantings (four environments) due to minimum juice yield.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.12 (c) of GGE Biplot. P-23 (G7), Carrot Nantes (G14), PCO-4 (G12) and Pusa Meghali (G16) and P-35 (G10) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes Carrot Early Nantes (G15), P-18 (G8) and P-3 (G1) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.12 (d) of GGE Biplot. The genotypes G7, G3, G11, G5, G13, G16, G12, G14 results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes Carrot Early Nantes (G15), P-3 (G1) and P-18 (G6) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3 Seed production potential of Carrot genotypes

4.3.1 Number of Branches

It has been depicted from table 4.6 that number of branches of carrot at the locations L1 (Ludhiana) and L2 (KVK Langroya) shown good performance but L1 has significantly higher no. of branches as compared to L2. Date of sowings also had significant effect on no. of branches. D2 (First week of January) showed significantly higher no. of branches and were significantly better over D1 (First week of December) and D3 (First week of February). The differed significantly due to genotypes. It ranged from 42.77-55.48. Genotype 14 (Pusa Meghali) have significantly higher no. of branches which was statistically at par with genotype P-3 (G1), genotype PCO-4 (G10) and significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for number of branches was given in Figure 4.13 (a). At location 1 (PAU, Ludhiana), the genotypes P-4 (G2), P-28 (G7), Carrot Nantes (G12) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely,

Table 4.6 Effects of locations, date of sowings and genotypes on number of branches, no. of primary umbels, no. of secondary umbels and no. of tertiary umbels.

		Number of branches	Number of primary umbels	Number of secondary umbels	Number of tertiary umbels
Locations	L1	50.39	1.00	9.36	40.02
	L2	47.43	1.00	11.27	35.03
	CD (5%)	1.66	NS	0.61	1.45
Date of sowings	D1	50.23	1.00	10.64	38.62
	D2	65.34	1.00	12.05	21.67
	D3	31.16	1.00	8.25	52.71
	CD (5%)	2.03	NS	0.75	1.77
Genotypes	G1	55.42	1.00	10.69	43.73
	G2	50.45	1.00	10.15	39.29
	G3	42.77	1.00	9.31	32.46
	G4	49.07	1.00	9.88	38.18
	G5	48.39	1.00	9.97	37.57
	G6	47.10	1.00	9.91	36.19
	G7	48.63	1.00	9.94	37.69
	G8	47.27	1.00	9.88	35.24
	G9	47.44	1.00	10.40	36.04
	G10	55.09	1.00	10.48	43.60
	G11	44.49	1.00	10.57	32.92
	G12	43.14	1.00	9.66	32.47
	G13	46.98	1.00	11.24	34.73
	G14	55.48	1.00	11.30	43.18
	G15	51.93	1.00	11.33	39.60
	CD(5%)	2.04	NS	0.68	1.78
	Locations × Date of sowings	2.87	NS	NS	2.51
	Locations × Genotypes	2.88	NS	0.96	2.52
	Date of sowings × Genotypes	3.53	NS	1.18	3.08
	Locations × Date of sowings × Genotypes	5.00	NS	1.67	4.36

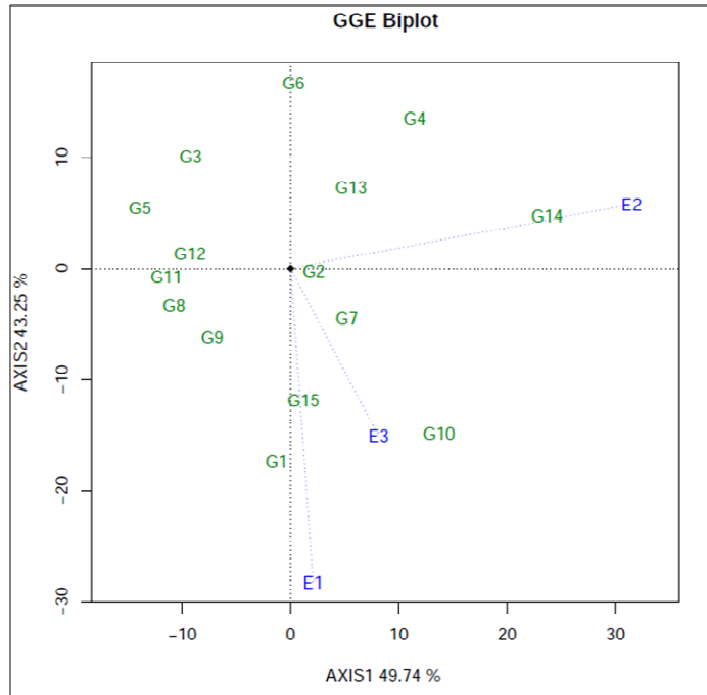


Fig 4.13 (a) GGE Biplot 1 for number of branches of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

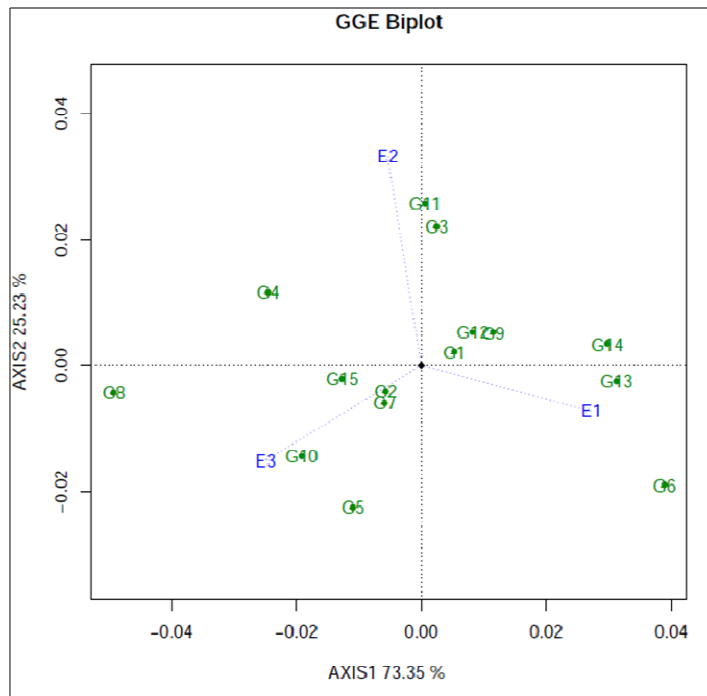


Fig 4.13 (b) GGE Biplot 1 for number of branches of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

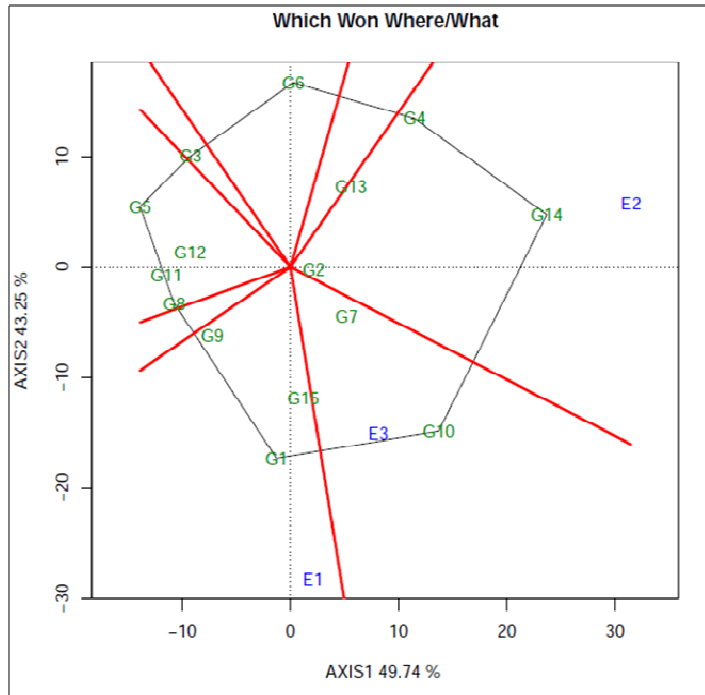


Fig 4.13 (c) What Won Where GGE Biplot for number of branches of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

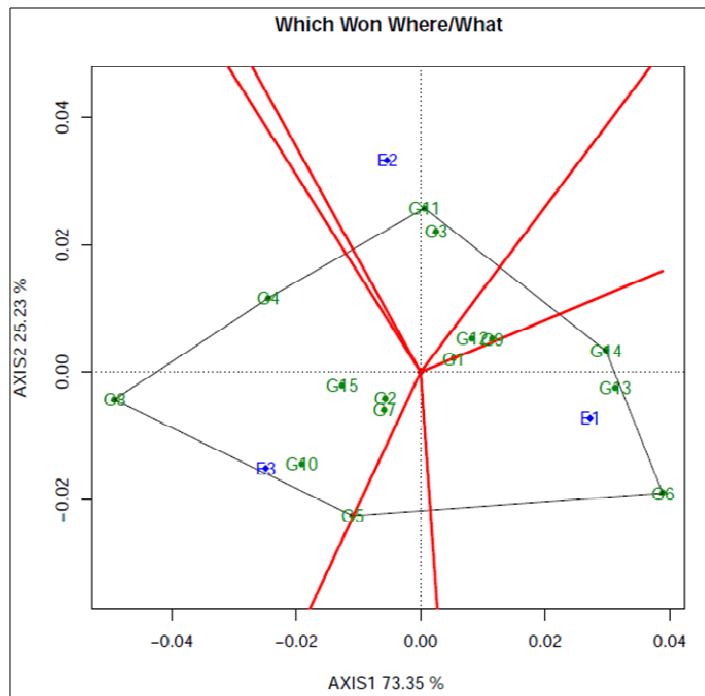


Fig 4.13 (d) What Won Where GGE Biplot for number of branches of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

P-3 (G1), P-16 (G4), Carrot Early Nantes (G13), Arka Suraj (G15) had maximum number of branches exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype Pusa Meghali (G14) was poor performers across the three plantings (three environments).

Fig. 4.13 (b) showed the GGE Biplot 1 performance of 15 genotypes and environments for number of branches of location 2. The genotypes P-4 (G2), P-3 (G1) and Arka Suraj (G15) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Arka Suraj (G4) and PCO-4 (G3) had maximum number of branches exhibiting adaptation to all four environments and therefore categorized as generalists. The genotype P-41 (G8) was poor performer across the three plantings (three environments) due to minimum number of branches.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.13 (c) of GGE Biplot. P-23 (G6), P-16 (G4), Pusa Meghali (G14), PCO-4 (G10) and P-3 (G1) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-4 (G2), P-28 (G7) and Carrot Early Nantes (G13) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.13 (d) of GGE Biplot. The genotypes G4, G6, G11, G5, G13, G12, G14 results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes Arka Suraj (G15), P-3 (G1) and P-4 (G2) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.2 Number of Primary umbels

From table 4.6 it has estimated that number of primary umbels of carrot at both the locations L1 (Ludhiana) and L2 (KVK Langroya) was non-significant to each other. Date of sowings also had non-significant effect on no. of primary umbels. There was no variation within genotypes and no. of primary branches were non significant.



Plate 1: Flowering in carrot genotypes at Ludhiana when stecklings were transplanted in 1st week of December



Plate 2: Flowering in carrot genotypes at KVK Langroya when stecklings were transplanted in 1st week of December



Plate 3: Flowering in carrot genotypes at Ludhiiana when stecklings were transplanted in 1st week of January



Plate 4: Flowering in carrot genotypes at KVK Langroya when stecklings were transplanted in 1st week of January



Plate 5: Flowering in carrot genotypes at Ludhiiana when stecklings were transplanted in 1st week of February

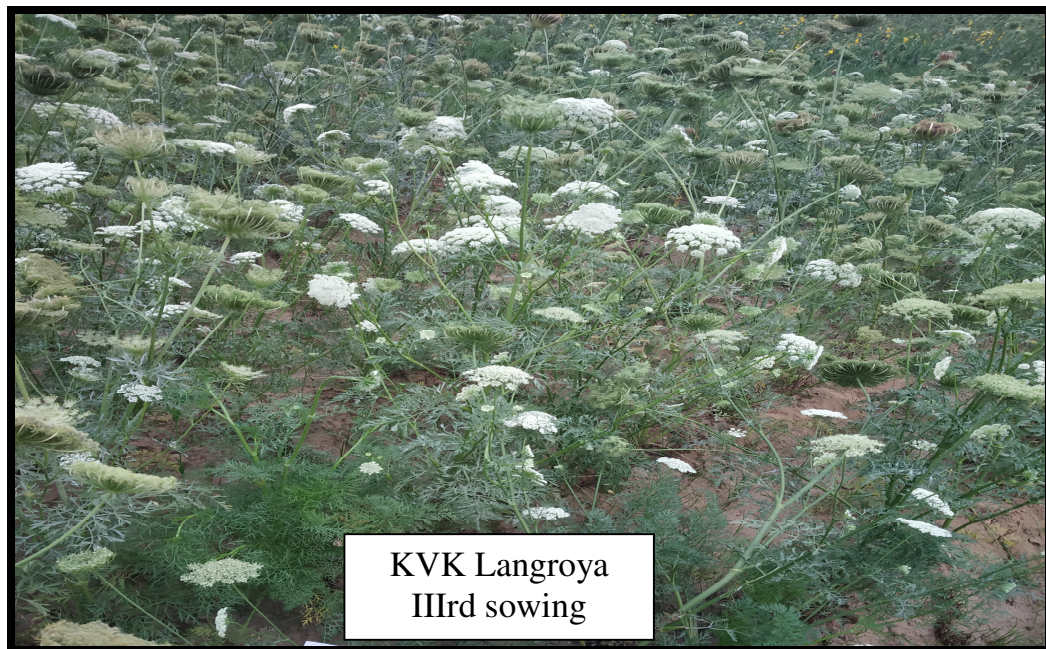


Plate 6: Flowering in carrot genotypes at KVK Langroya when stecklings were transplanted in 1st week of February



Vegetative phase of stecklings



Umbel formation



Seed setting in umbel



Stage of harvesting

Plate 7: Seed production stages in European carrot

4.3.3 Number of Secondary umbels

It has been depicted from table 4.6 that number of secondary umbels of carrot at locations L1 (Ludhiana) and L2 (KVK Langroya), the number of secondary umbels of carrot was significantly better in L2 (11.27) as compared to L1 (9.36). Date of sowings also had significant effect on the number of secondary umbels. D2 (First week on January) showed significantly higher number of secondary umbels which was statistically at par with D1 (First week of December) and significantly better over D3 (First week of February). The number of secondary umbels differed significantly due to genotypes. It ranged from 9.31 to 11.33. Genotype 15 showed the maximum (11.33) number of secondary umbels which was statistically at par with genotype 1 (10.69) and significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for number of secondary umbels was given in Figure 4.14 (a). At location 1 (PAU, Ludhiana), the genotypes P-16 (G4), PCO-4 (G10), P-23 (G6) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-4 (G2) and P-18 (G5) had maximum number of secondary umbels exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype Arka Suraj (G15) was poor performers across the three plantings (three environments).

Fig. 4.14 (b) showed the GGE Biplot 1 performance of 15 genotypes and environments for number of secondary umbels of location 2. The genotypes P-18 (G5) and PCO-4 (G10) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-3 (G1), P-41 (G9) and Pusa Meghali (G14) had maximum number of secondary umbels exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype Carrot Nantes (G12) was poor performer across the three plantings (three environments) due to minimum number of secondary umbels.

GGE Biplot 2

Number of secondary umbels described through the stability of genotypes and environments (sowings), as well as specific G×E interaction at location1 in Figure 4.14 (c) of GGE Biplot. P-5 (G3), P-29 (G8), P-28 (G7) and Carrot Nantes (G12) and PCO-6 (G11), P-18 (G5), Carrot Early Nantes (G13) and Pusa Meghali (G14) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-3 (G1), PCO-4 (G10) and P-41 (G9) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the

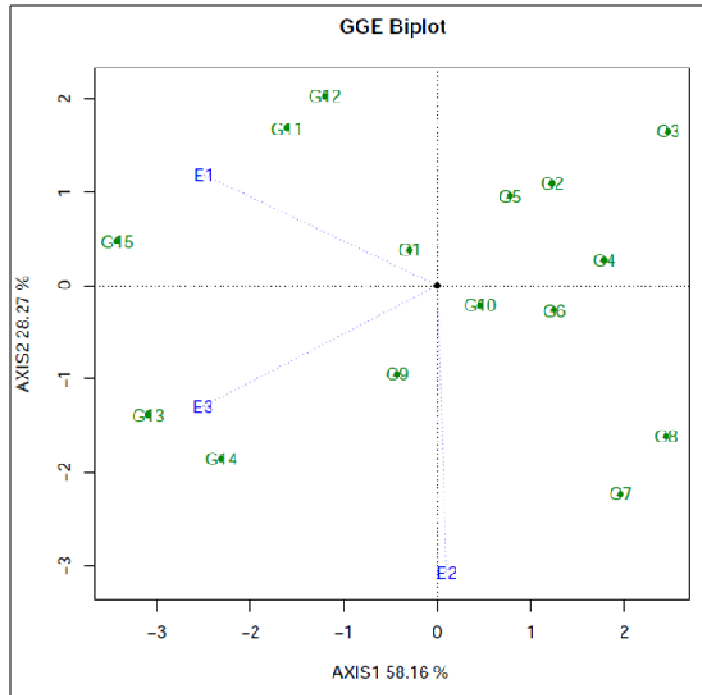


Fig 4.14 (a) GGE Biplot 1 for Number of secondary umbels of Carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

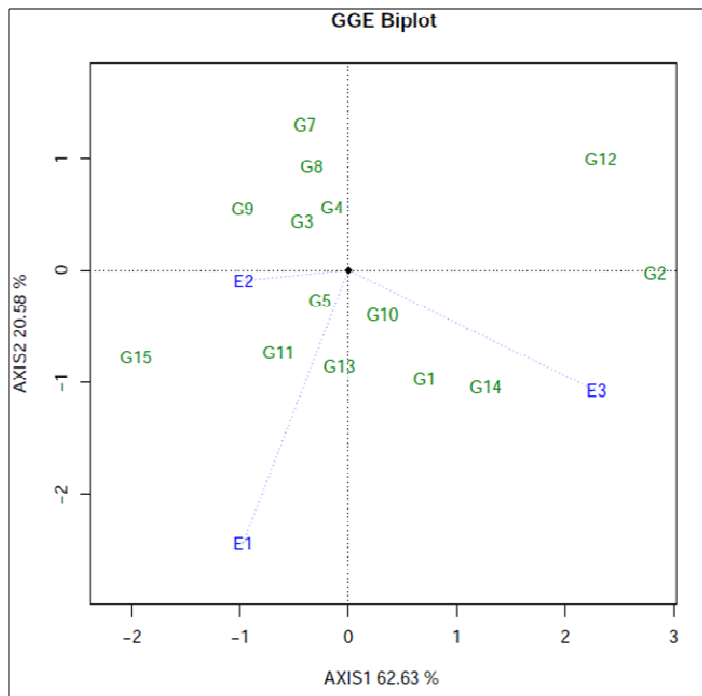


Fig 4.14 (b) GGE Biplot 1 for number of secondary umbels of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

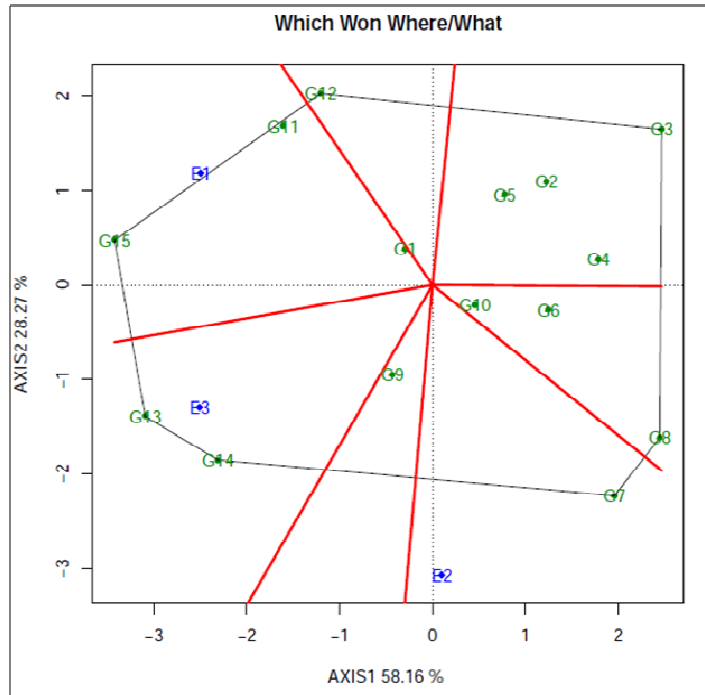


Fig 4.14 (c) What Won Where GGE Biplot for number of secondary umbels of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

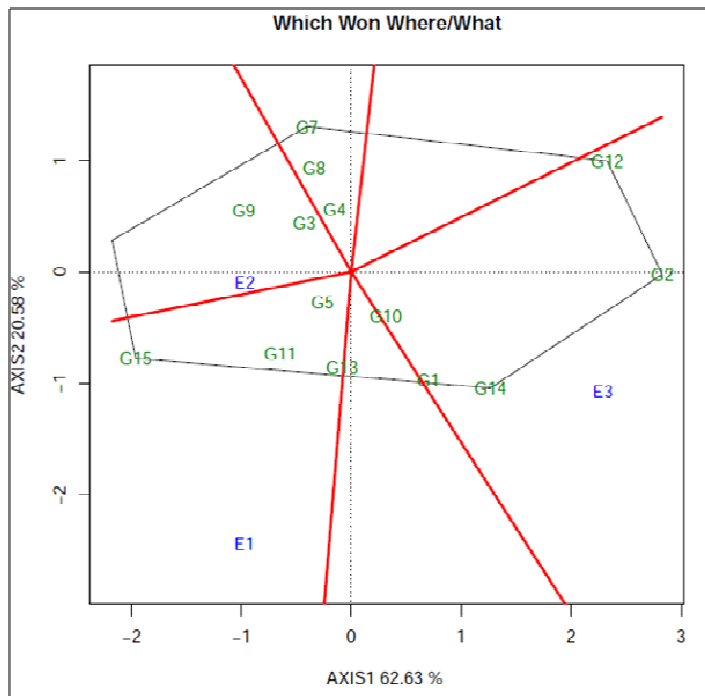


Fig 4.14 (d) What Won Where GGE Biplot for number of secondary umbels of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK,Langroya)

environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.14 (d) of GGE Biplot for number of secondary umbels. The genotypes Carrot Nantes (G12), P-4 (G2), Pusa Meghali (G14), Carrot Early Nantes (G13), Arka Suraj (G15), P-28 (G7) results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-18 (G5) and PCO-4 (G10) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.4 Number of Tertiary umbels

Table 4.6 depicted that the locations L1 (Ludhiana) and L2 (KVK Langroya), the number of tertiary umbelsof carrot was significantly better in L2 (35.03) as compared to L1 (40.02). Date of sowings also had significant effect on the number oftertiary umbels. D3 (First week on February) showed significantly higher number of tertiary umbels than D1 and D2. The number of tertiary umbels differed significantly due to genotypes. It ranged from 32.46 to 43.73. Genotype 3 showed the maximum (32.46) number of tertiary umbels and significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for number of tertiary umbels was given in Figure 4.15 (a). At location 1 (PAU, Ludhiana), the genotypes8 (P-29) and genotype 9 (P-41) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Arka Suraj (G15), Carrot Nantes (P-12), PCO-6 (G11) and Carrot Early Nantes (G13) had maximum number of tertiary umbels exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype Pusa Meghali (G14) was poor performers across the three plantings (three environments).

Fig. 4.15 (b) showed the GGE Biplot 1 performance of 15 genotypes and environments for number of tertiary umbels of location 2. The genotypes Arka Suraj (G15), P-3 (G1) and PCO-4 (G10) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Early Nantes (G13), Carrot Nantes (G12) and P-29 (G8) had maximum number of tertiary umbels exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype P-23 (G6) was poor performe across the three plantings (three environments) due to minimum number of tertiary umbels.

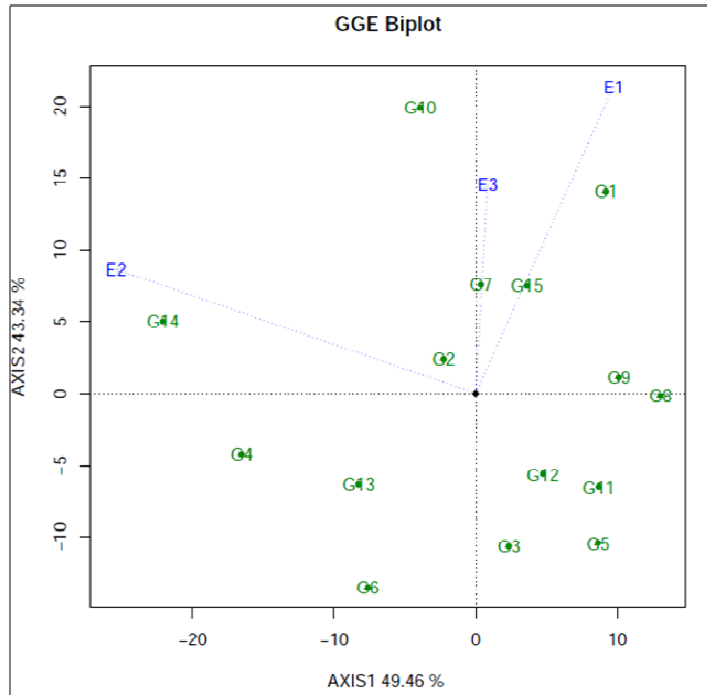


Fig 4.15 (a) GGE Biplot 1 for number of tertiary umbels of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

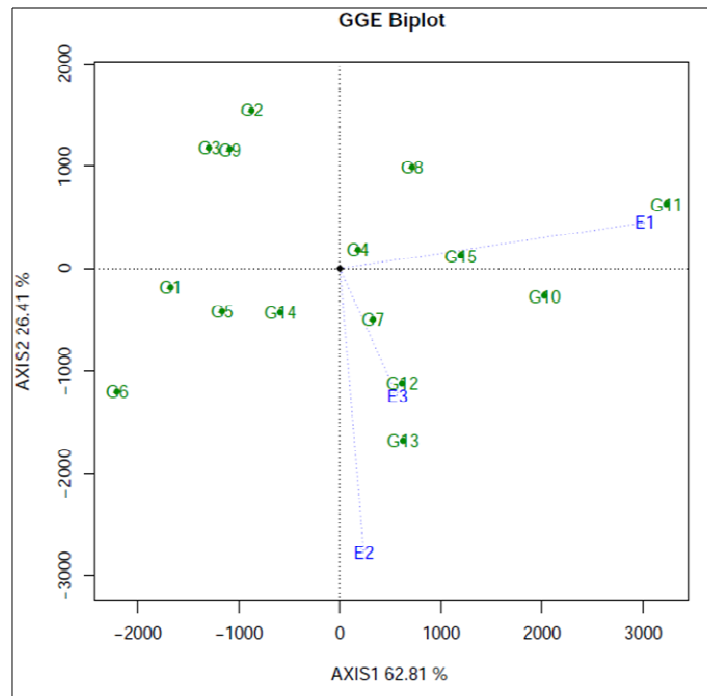


Fig 4.15 (b) GGE Biplot 1 for number of tertiary umbels of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

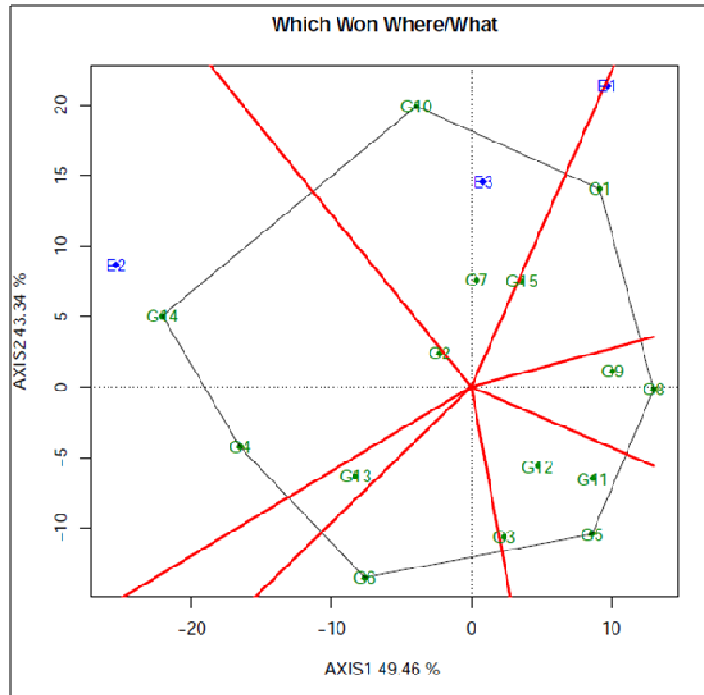


Fig 4.15 (c) What Won Where GGE Biplot for number of tertiary umbels of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

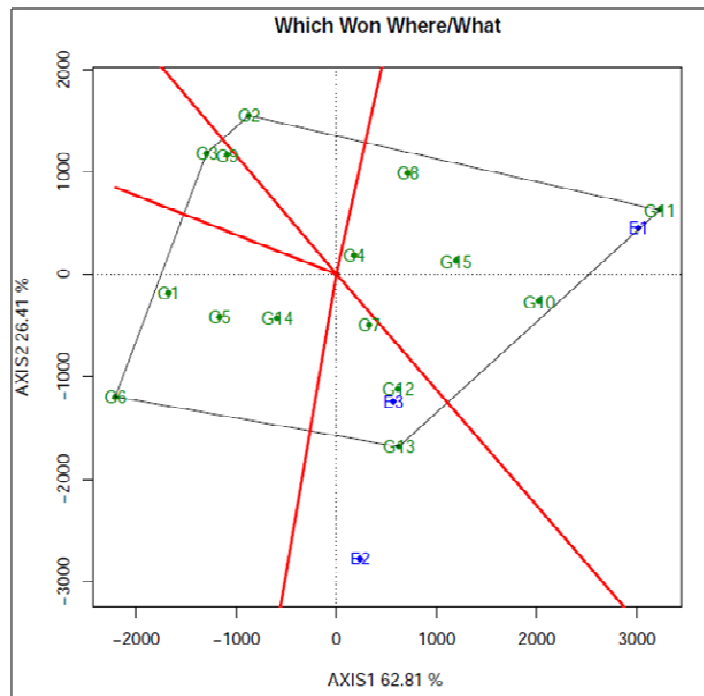


Fig 4.15 (d) What Won Where GGE Biplot for number of tertiary umbels of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK,Langroya)

GGE Biplot 2

Number of tertiary umbels described through the stability of genotypes and environments (sowings), as well as specific G×E interaction at location1 in Figure 4.15 (c) of GGE Biplot. P-3 (G1), P-29 (G8), P-23 (G6), P-18 (G5), P-4 (G4), Pusa Meghali (P-14) and PCO-4 (G10) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-4 (G2) and P-28 (G7) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.15 (d) of GGE Biplot for number of tertiary umbels. The genotypes PCO-6 (G11), Carrot Early Nantes (G13), P-23 (G6), P-5 (G3), P-41 (G9), P-4 (G2) results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-16 (G4), P-28 (G7) and Pusa Meghali (G14) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.5 No. of seeds per plant

From both the locations L1 (Ludhiana) and L2 (KVK Langroya), the No. of seeds per plant of carrot was significantly better in L2 (5699.11) as compared to L1 (5629.12). Date of sowings also had significant effect on number of seeds per plant. D1 (First week on December) showed significantly higher number of seeds per plant which was statistically at par with D2 (First week of January) and significantly better over D3 (First week of February). The number of seeds per plant differed significantly due to genotypes. It ranged from 4899.16 to 6608.24 .Genotype 10 showed the maximum (6608.24) number of seeds per plant which was statistically at par with genotype 7(5821.41) and genotype 13 (6071.54) significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for number of seeds per plant was given in Figure 4.16 (a). At location 1 (PAU, Ludhiana), the genotypes P-23 (G6), PCO-6 (G11), P-41 (G9) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-29 (G8), P-16 (G4), P-5 (G3), P-3 (G1) had maximum number of seeds per plant exhibiting

Table 4.7 Effects of location, Date of sowing and genotypes on no. of seeds per plant, seed weight per plant, 100 seed weight, seed yield per hectare (kg) and seedling dry weight:

		No. of Seeds per plant	Seed weight (g) per plant	100 seed weight (g)	Seed yield per hectare (kg)	Seedling dry weight (g)
Locations	L1	5629.12	11.96	0.16	349.88	0.0083
	L2	5699.11	12.73	0.17	397.19	0.010
	CD (5%)	NS	0.27	0.0072	12.80	0.0016
Date of sowings	D1	7545.71	14.13	0.18	478.38	0.0086
	D2	6621.96	12.76	0.16	430.43	0.011
	D3	2824.68	10.15	0.16	211.80	0.0071
	CD (5%)	448.24	0.33	0.0088	15.68	0.0020
Genotypes	G1	5351.23	10.50	0.15	318.57	0.0072
	G2	4930.59	10.73	0.17	337.39	0.0081
	G3	4899.16	11.21	0.16	318.57	0.0078
	G4	5622.14	11.97	0.16	367.96	0.0074
	G5	5248.17	12.00	0.17	348.61	0.010
	G6	5327.60	12.03	0.16	338.09	0.0097
	G7	5821.41	12.37	0.16	390.19	0.0097
	G8	5798.50	11.91	0.16	368.86	0.0085
	G9	5340.95	11.80	0.17	355.91	0.0093
	G10	6608.24	13.84	0.17	428.87	0.0087
	G11	6578.43	14.35	0.18	450.40	0.0095
	G12	6380.65	13.78	0.17	432.10	0.0093
	G13	6071.54	13.55	0.16	403.87	0.0087
	G14	5630.21	12.80	0.16	372.38	0.012
	G15	5352.90	12.37	0.18	371.27	0.011
	CD(5%)	684.48	0.87	0.0077	37.07	NS
	Locations × Date of sowings	633.91	0.47	0.012	NS	NS
	Locations × Genotypes	NS	1.23	0.010	52.43	NS
	Date of sowings × Genotypes	1185.56	1.51	0.013	64.22	0.0065
	Locations × Date of sowings × Genotypes	1676.64	2.13	0.019	90.82	NS

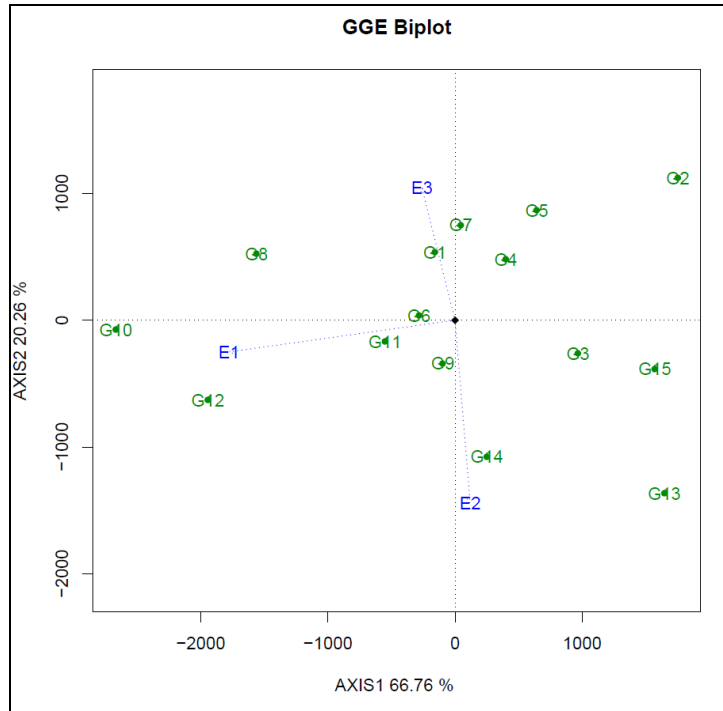


Fig 4.16 (a) GGE Biplot 1 for no. of seeds per plant of carrot showing the interaction of 15 genotypes in 3 environments of locations L1

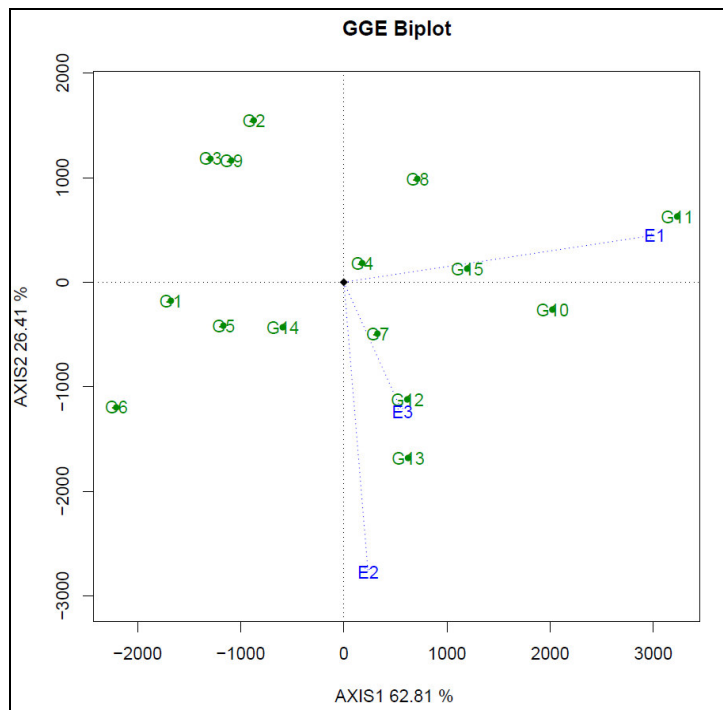


Fig 4.16 (b) GGE Biplot 1 for no. of seeds per plant of carrot showing the interaction of 15 genotypes in 3 environments of locations L2

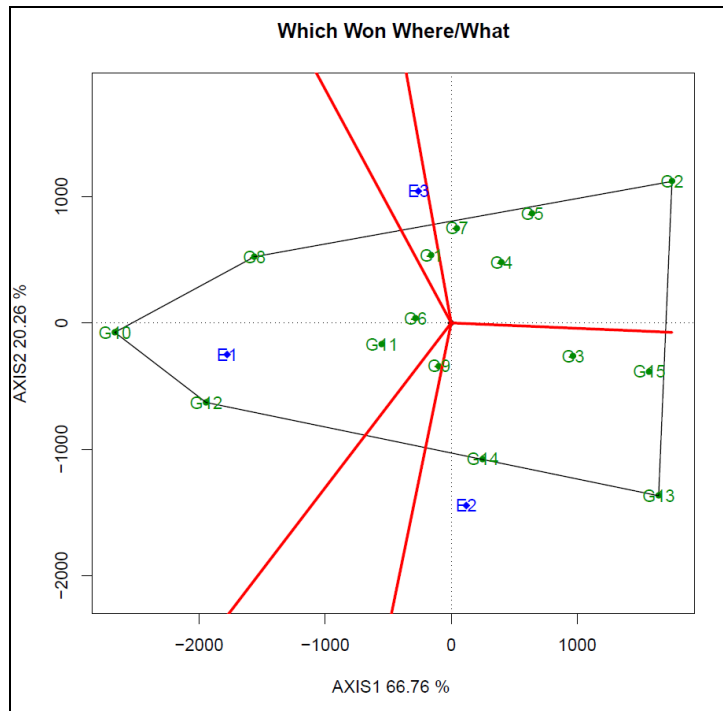


Fig 4.16 (c) Which Won Where GGE Biplot for no. of seeds per plant of carrot showing the interaction of 15 genotypes in 3 environments of locations L1

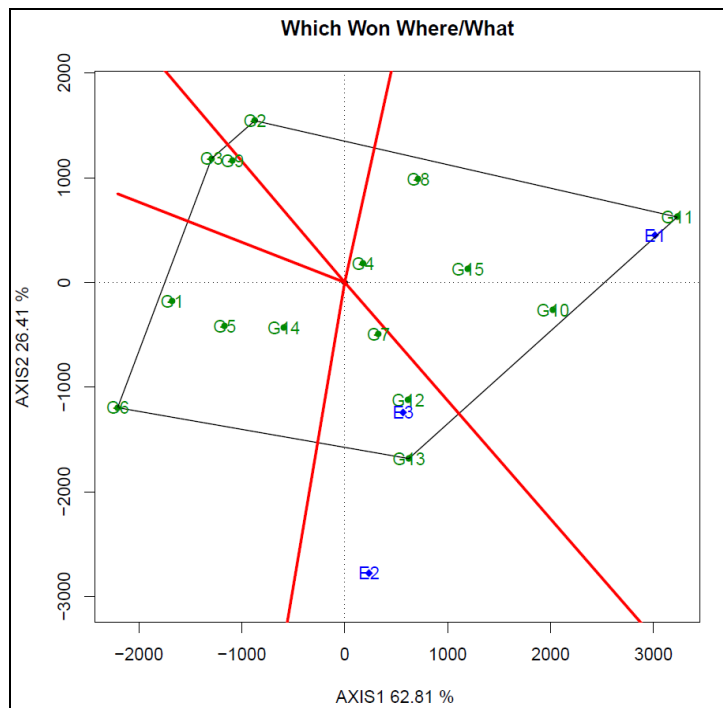


Fig 4.16 (d) Which Won Where GGE Biplot for no. of seeds per plant of carrot showing the interaction of 15 genotypes in 3 environments of locations L2

adaptation to all three environments and therefore categorized as generalists. The genotype and P-4 (G2), Carrot Early Nantes (G13), PCO-4 (G10) were poor performers across the three plantings (three environments).

Fig. 4.16 (b) showed the GGE Biplot 1 performance of 17 genotypes and environments for number of seeds per plant of location 2. The genotypes P-16 (G4), Arka Suraj (G15) and Pusa Meghali (G14) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-23 (G6), P-28 (G7), PCO-4 (G10) and P-18 (G5) had maximum number of seeds per plant exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype P-23 (G6) and PCO-6 (G11) were poor performers across the three plantings (three environments) due to minimum number of seeds per plant.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.16 (c) of GGE Biplot. PCO-4 (G10), Carrot Nantes(G12), Carrot Early Nantes (G13) and P-4 (G2) and P-29 (G8) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-23 (G6), P-41 (G9) and PCO-6 (G11) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.16 (d) of GGE Biplot. The genotypes P-23 (G6), Carrot Early Nantes (G13), PCO-6 (G11), P-4 (G2), P-5 (G3) results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-16 (G4), P-28 (G7) and Pusa Meghali (G14) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.6 Seed weight per plant

While comparing both the locations L1 (Ludhiana) and L2 (KVK Langroya), the seed weight per plant of carrot was significantly better in L2 (12.73) as compared to L1 (11.96). Date of sowings also had significant effect on seed weight per plant. D1 (First week on December) showed significantly higher seed weight per plant which was significantly better

over D2 (First week of January) and D3 (First week of February) dates of sowing. The seed weight per plant differed significantly due to genotypes. It ranged from 10.50 to 14.35g. Genotype 11 showed the maximum (14.35g) seed weight per plant which was statistically at par with genotype 10 (13.84g), genotype 12 (13.78 g) and genotype 13 (13.55 g) and were significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for seed weight per plant was given in Figure 4.17 (a). At location 1 (PAU, Ludhiana), the genotypes P-41 (G9), Arka Suraj (G15), P-23 (G6) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Pusa Meghali (G14), P-29 (G8), PCO-6 (G11), Carrot Nantes (G12) had maximum seed weight per plant exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype and P-16 (G4), P-18 (G5), Carrot Early Nantes (G13) were poor performers across the three plantings (three environments).

Fig. 4.17 (b) showed the GGE Biplot 1 performance of 17 genotypes and environments for seed weight per plant of location 2. The genotypes P-28 (G7), Pusa Meghali (G14), P-18 (G5) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Arka Suraj (G15), P-16 (G4), P-4 (G2) and Carrot Early Nantes (G13) had maximum number of seeds per plant exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype P-3 (G1) and PCO-6 (G11) were poor performers across the three plantings (three environments) due to minimum seed weight per plant.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.17 (c) of GGE Biplot. P-16 (G4), P-18 (G5), PCO-4 (G10) and PCO-6 (G11), Carrot Early Nantes (G13) and Carrot Nantes (G12) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-41 (G9), Pusa Meghali (G14) and Arka Suraj (G15) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.14 (d) of GGE Biplot. The genotypes P-3 (G1), PCO-4 (G10), PCO-6 (G11), Carrot Nantes (G12), P-5 (G3), P-16 (G4) results in polygon and had highest vectors in their particular direction) from biplot point of

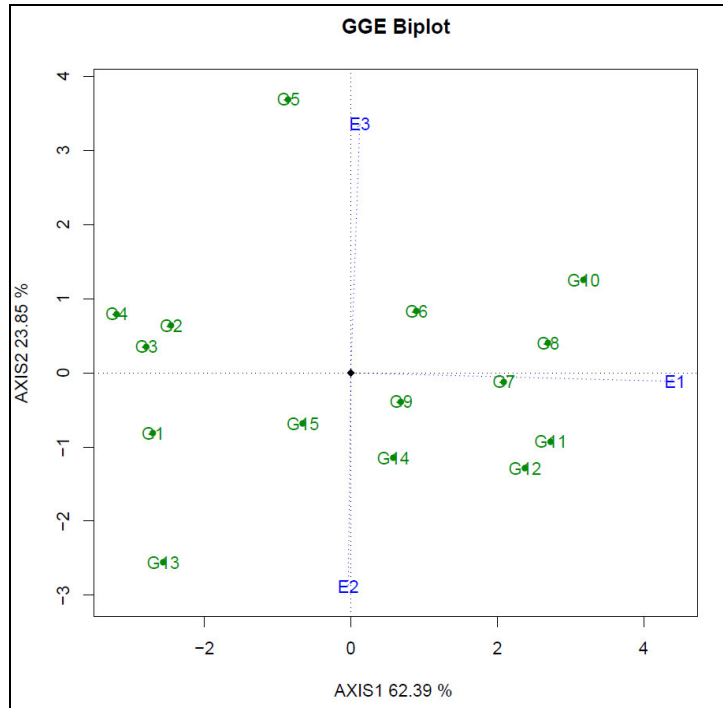


Fig 4.17 (a) GGE Biplot 1 for seed weight per plant of carrot showing the interaction of 15 genotypes in 3 environments of locations L1

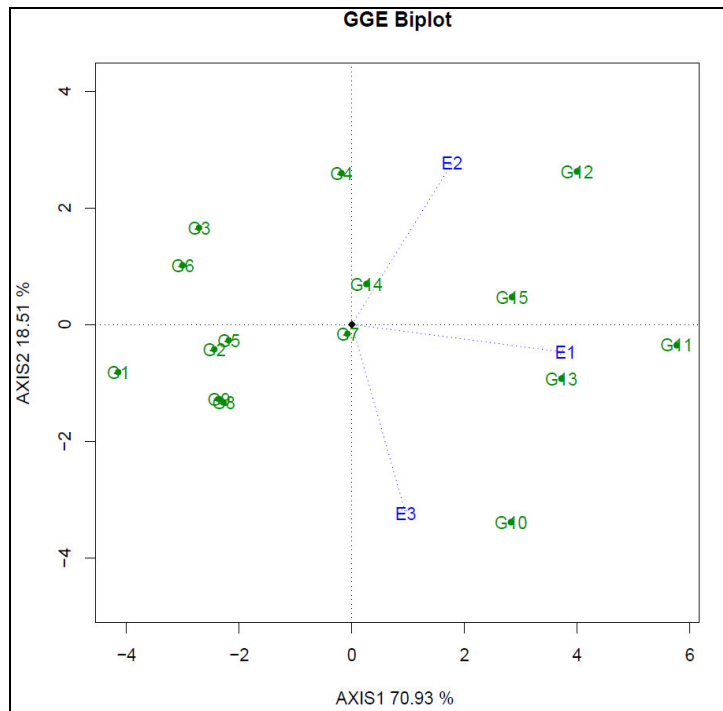


Fig 4.17 (b) GGE Biplot 1 for seed weight per plant of carrot showing the interaction of 15 genotypes in 3 environments of location L2

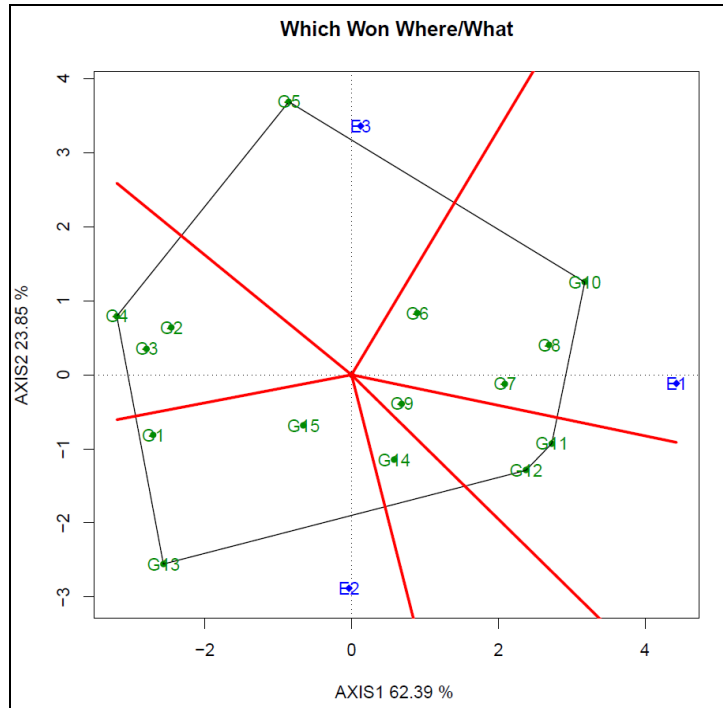


Fig 4.17 (c) Which Won Where GGE Biplot for seed weight per plant of carrot showing the interaction of 15 genotypes in 3 environments of locations L1

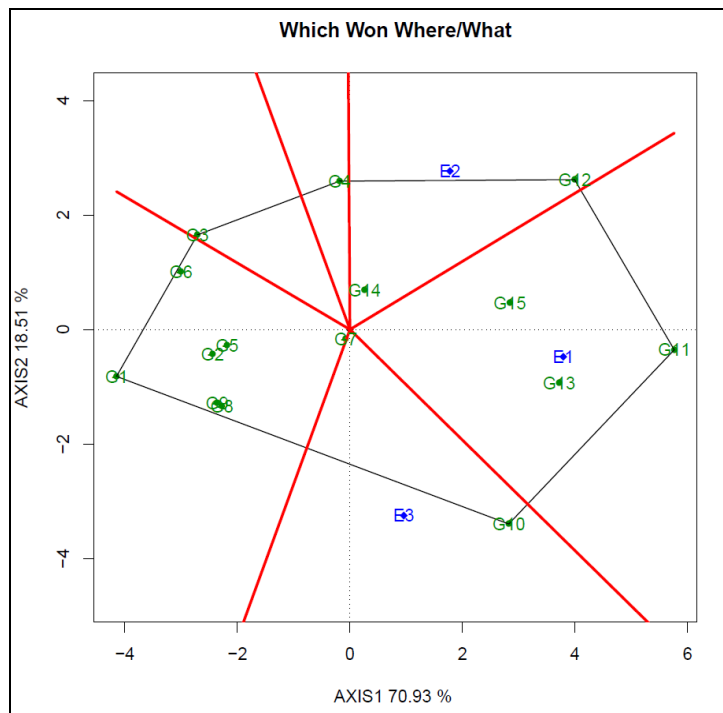


Fig 4.17 (d) Which Won Where GGE Biplot for seed weight per plant of carrot showing the interaction of 15 genotypes in 3 environments of location L2

origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-28 (G7), P-18 (G5) and Pusa Meghali (G14) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.7 100 Seed weight

At locations L1 (Ludhiana) and L2 (KVK Langroya), the 100 seed weight of carrot was significantly better in L2 (0.17) as compared to L1 (0.16). Date of sowings also had significant effect on 100 seed weight. D1 (First week on December) showed significantly higher 100 seed weight and D2 (First week of January) was statistically at par with D3 (First week of February). The 100 seed weight differed significantly due to genotypes. It ranged from 0.15 to 0.18. Genotype 11 and genotype 15 showed the maximum (0.18) 100 seed weight which was statistically at par with genotype 2, 5, 9, 10, 12 (0.17) and significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for 100 seed weight was given in Figure 4.18 (a). At location 1 (PAU, Ludhiana), the genotypes P-3 (G1), P-4 (G2), Carrot Nantes (G12) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, PCO-4 (G10), P-16 (G4), P-5 (G3), P-28 (G7) had maximum 100 seed weight exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype and P-29 (G8), P-23 (G6) were poor performers across the three plantings (three environments).

Fig. 4.18 (b) showed the GGE Biplot 1 performance of 17 genotypes and environments for 100 seed weight of location 2. The genotypes P-28 (G7), P-18 (G5) and Carrot Nantes (G12) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Arka Suraj (G15), P-16 (G4), P-29 (G8) and P-41 (G9) had maximum 100 seed weight exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype Pusa Meghali (G14) and P-3 (G1) were poor performers across the three plantings (three environments) due to minimum 100 seed weight.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.18 (c) of GGE Biplot. P-29 (G8), P-18 (G5), P-23 (G6) and Pusa Meghali (G14) and PCO-6 (G11) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had

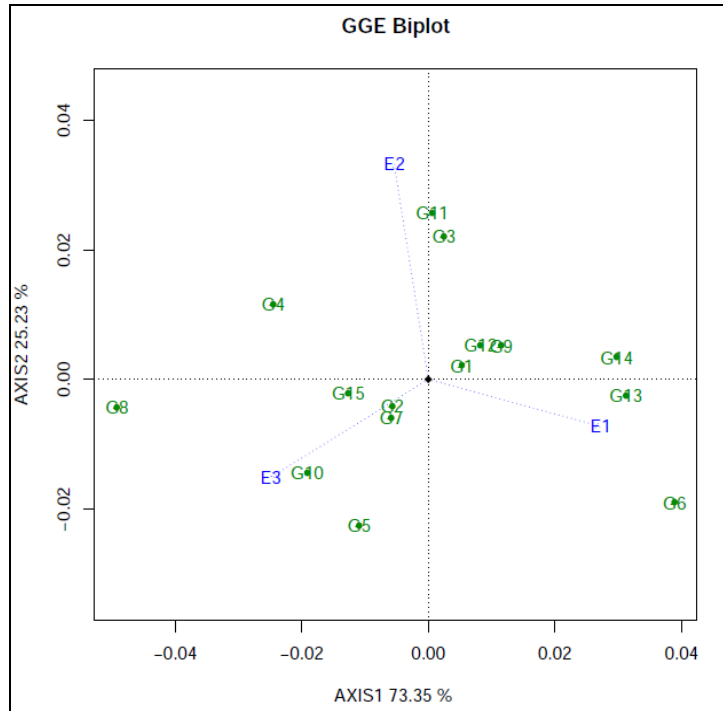


Fig 4.18 (a) GGE Biplot 1 for 100 seed weight of carrot showing the interaction of 15 genotypes in 3 environments of locations L1

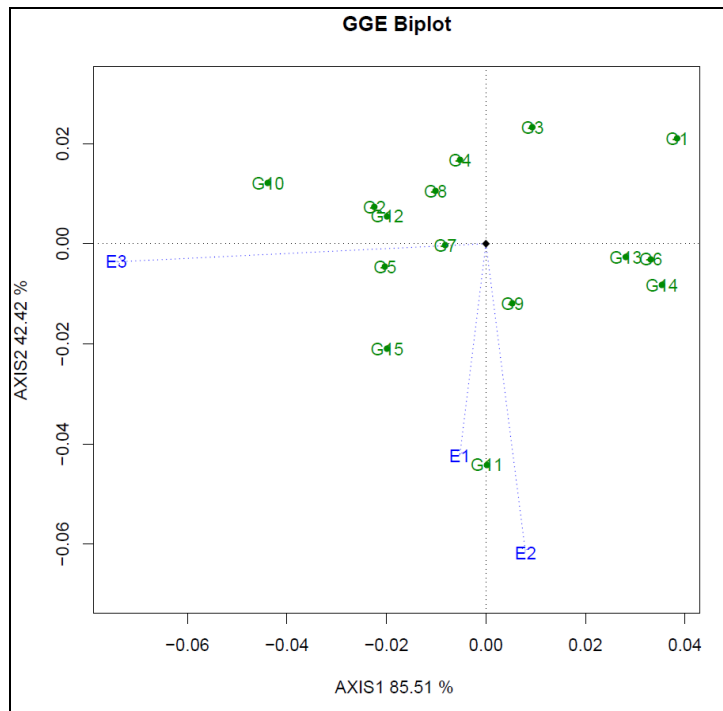


Fig 4.18 (b) GGE Biplot 1 for 100 seed weight of carrot showing the interaction of 15 genotypes in 3 environments of location L2

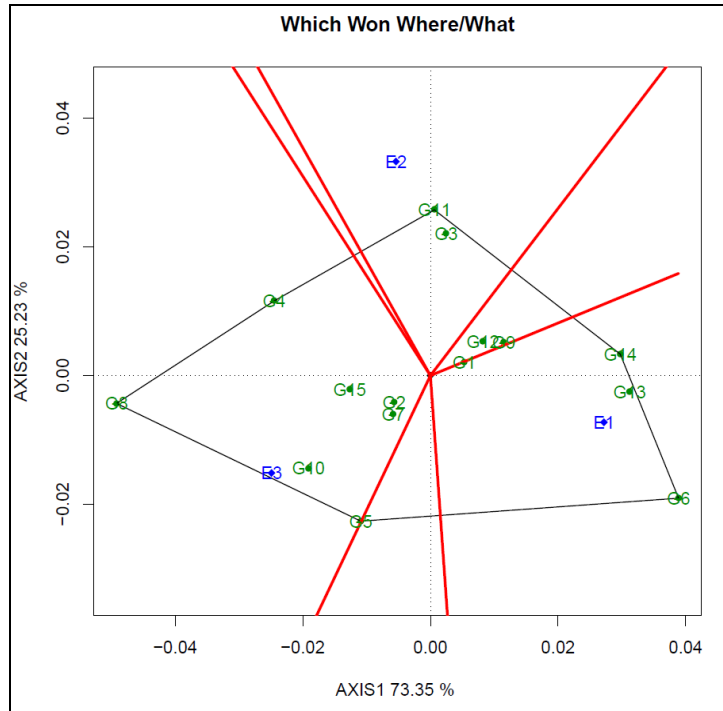


Fig 4.18 (c) Which Won Where GGE Biplot for 100 seed weight of carrot showing the interaction of 15 genotypes in 3 environments of locations L1

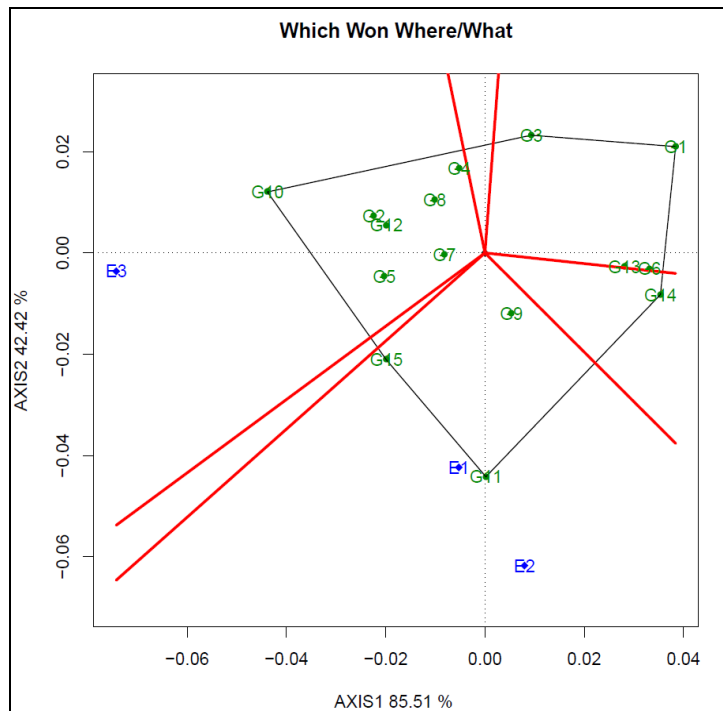


Fig 4.18 (d) Which Won Where GGE Biplot for 100 seed weight of carrot showing the interaction of 15 genotypes in 3 environments of location L2

smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-3 (G1), P-4 (G2) and Carrot Nantes(G12) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.18 (d) of GGE Biplot. The genotypes PCO-4 (G10), PCO-6 (G11), P-3 (G1), Pusa Meghali (G14), P-5 (G3) results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-18 (G5), P-28 (G7) and Carrot Nantes (G12) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.8 Seed yield per hectare (kg)

By comparing both the locations L1 (Ludhiana) and L2 (KVK Langroya), the seed yield per hectare of carrot was significantly better in L2 (397.19) as compared to L1 (349.88). Date of sowings also had significant effect on seed yield per hectare. D1 (First week on December) showed significantly higher seed yield per hectare which was statistically at par with D2 (First week of January) and significantly better over D3 (First week of February). The seed yield per hectare differed significantly due to genotypes. It ranged from 318.57 to 450.40 . Genotype 11 showed the maximum (450.40) seed yield per hectare which was statistically at par with genotype 10 (428.87) and genotype 12 (432.10) and significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for 100 seed yield per hectare was given in Figure 4.19 (a). At location 1 (PAU, Ludhiana), the genotypes Carrot Early Nantes (G13), P-41 (G9), P-18 (G5) and PCO-6 (G12) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-29 (G8), P-28 (G7), PCO-4 (G10) and PCO-6 (G11) had maximum seed yield per hectare exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype P-23 (G6) was poor performers across the three plantings (three environments).

Fig. 4.19 (b) showed the GGE Biplot 1 performance of 17 genotypes and environments for seed yield per hectare of location 2. The genotypes P-29 (G8), P-28 (G7), Pusa Meghali (G14), Carrot Early Nantes (G13) and Arka Suraj (G15) showed stable

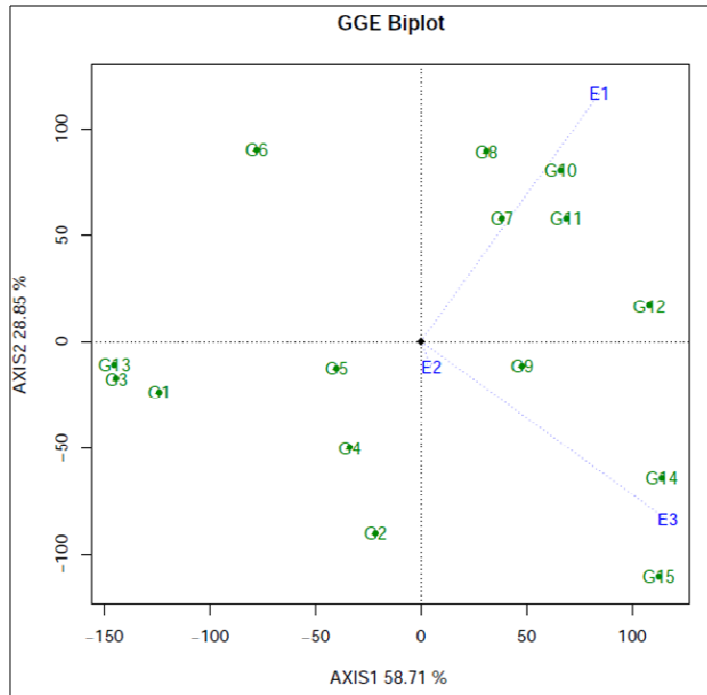


Fig 4.19 (a) GGE Biplot 1 for seed yield per hectare of carrot showing the interaction of 15 genotypes in 3 environments of locations L1 (Ludhiana)

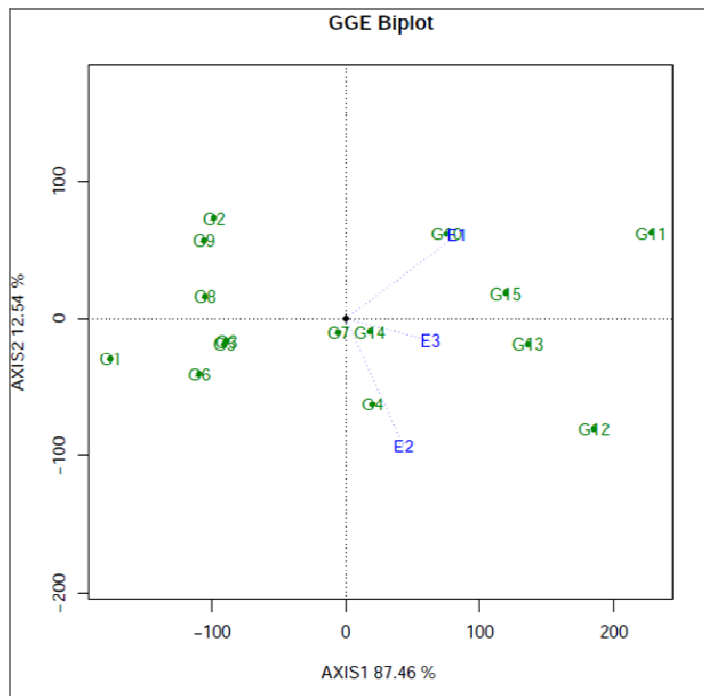


Fig 4.19 (b) GGE Biplot 1 for seed yield per hectare of carrot showing the interaction of 15 genotypes in 3 environments of locations L2 (KVK, Langroya)

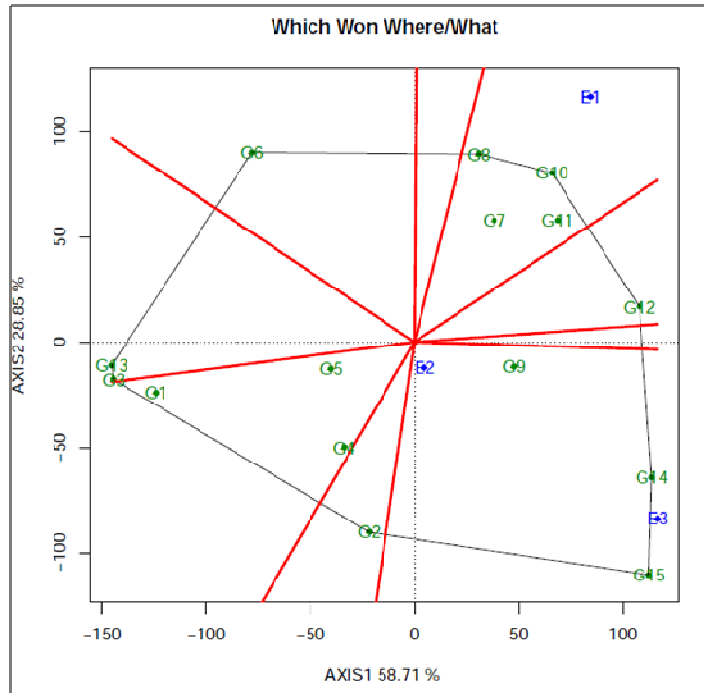


Fig 4.19 (c) Which Won Where GGE Biplot of seed yield per hectare of carrot showing the interaction of 15 genotypes in 3 environments of locations L1 (Ludhiana)

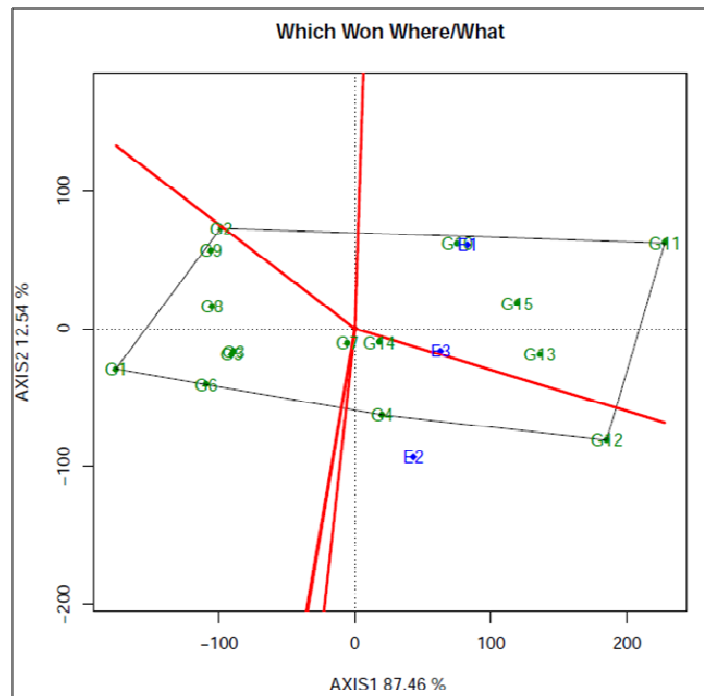


Fig 4.19 (d) Which Won Where GGE Biplot of seed yield per hectare of carrot showing the interaction of 15 genotypes in 3 environments of locations L1 (KVK, Langroya)

performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-16 (G4) and PCO-6 (G11) had maximum seed yield per hectare exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype P-4 (G2) and P-41 (G9) were poor performers across the three plantings (three environments) due to minimum 100 seed weight.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.19 (c) of GGE Biplot. P-23 (G6), PCO-4 (G10), Carrot Nantes (G12), Arka Suraj (G15), P-4 (G2) and Carrot Early Nantes (G13) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-18 (G5) and P-41 (G9) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.19 (d) of GGE Biplot. The genotypes P-4 (G2), PCO-6 (G11), Carrot Nantes (G12), P-16 (G4), P-23 (G6) and P-3 (G1) results in polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-28 (G7) and Pusa Meghali (G14) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.9 Seedling dry weight

Among both the locations L1 (Ludhiana) and L2 (KVK Langroya), the seedling dry weight of carrot was significantly better in L2 (0.010) as compared to L1 (0.0083). Date of sowings also had significant effect on seedling dry weight. D2 (First week of January) showed significantly higher seedling dry weight than other Date of sowings. The seedling dry weight differed significantly due to genotypes. Genotype 5, genotype 14, genotype 15 showed the maximum seedling dry weight and significantly better over all other genotypes.

4.3.10 Germination (%)

Table 4.8 showed that from the locations L1 (Ludhiana) and L2 (KVK Langroya), the germination % of European carrot was significantly better in L2 (76.97) as compared to L1 (71.96). Date of sowings also had significant effect on germination %. D2 (First week on

January) showed significantly higher germination % which was statistically at par with D1 (First week of December) and significantly better over D3 (First week of February). The germination % differed significantly due to genotypes. It ranged from 65.61 to 84.72. Genotype 8 (P-28) showed the maximum (84.72) which was statistically at par with genotype 12 (PCO-4) (79.55) and significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for germination % was given in Figure 4.20 (a). At location 1 (PAU, Ludhiana), the genotypes P-3 (G1), Pusa Meghali (G14), Arka Suraj (G15) and P-16 (G4) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-4 (G2) and P-5 (G3) had maximum germination % exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype and P-29 (G8) were poor performers across the three plantings (three environments).

Fig. 4.20 (b) showed the GGE Biplot 1 performance of 17 genotypes and environment for germination % of location 2. The genotypes P-3 (G1), P-41 (G9) and P-16 (G4) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-4 (G2) and Arka Suraj (G15) had maximum number of seeds per plant exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype P-5(G3) was poor performers across the three plantings (three environments) due to minimum speed of germination.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.20 (c) of GGE Biplot. P-29 (G8), Carrot Nantes (G12), P-16 (G4), PCO-4 (G10) and P-28 (G7) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes Pusa Meghali (G14) and Arka Suraj (G15) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.20 (d) of GGE Biplot. The genotypes P-3 (G1), P-5 (G3), PCO-4 (G10), Carrot Nantes (G12) and P-23 (G6) results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less

Table 4.8 Effects of location, date of sowing and genotypes on germination %, speed of germination, seedling length, vigour index I and vigour index 2

		Germination (%)	Speed of germination	Seedling length (cm)	Vigour index I	Vigour index 2
Locations	L1	71.96	5.04	12.86	927.75	0.61
	L2	76.97	5.76	14.08	1084.10	0.78
	CD (5%)	3.14	0.12	0.27	48.62	0.13
Date of sowings	D1	73.64	5.73	13.85	946.58	0.64
	D2	79.97	5.56	13.74	1101.41	0.94
	D3	69.78	4.90	12.82	969.78	0.50
	CD (5%)	3.84	0.15	0.33	59.54	0.16
Genotypes	G1	77.11	5.16	12.95	1005.01	0.58
	G2	70.77	5.22	12.73	898.24	0.58
	G3	65.61	5.55	13.89	911.77	0.53
	G4	73.16	5.08	13.84	1016.89	0.55
	G5	70.66	5.62	13.51	942.58	0.73
	G6	77.11	5.45	14.01	1079.47	0.75
	G7	76.55	5.34	13.27	1017.25	0.76
	G8	84.72	5.28	13.95	1182.26	0.72
	G9	77.00	5.63	13.43	1036.75	0.72
	G10	73.05	6.08	13.78	1018.88	0.65
	G11	75.88	5.54	12.76	968.49	0.73
	G12	79.55	5.42	12.61	1010.25	0.74
	G13	74.77	5.60	13.39	1010.46	0.66
	G14	72.11	4.95	13.94	1017.37	0.95
	G15	68.94	5.03	13.99	973.21	0.79
	CD(5%)	3.71	0.37	0.56	67.22	NS
	Locations × Date of sowings	NS	0.22	0.47	NS	NS
	Locations × Genotypes	NS	NS	0.79	95.06	NS
	Date of sowings × Genotypes	6.43	0.65	0.97	116.43	0.49
	Locations × Date of sowings × Genotypes	9.09	0.92	1.37	164.66	NS

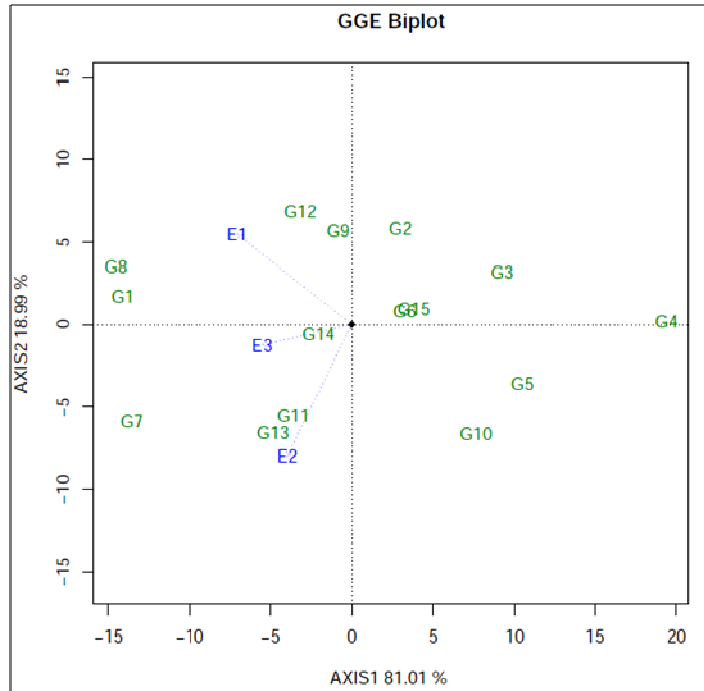


Fig 4.20 (a) GGE Biplot 1 for germination (%) of carrot showing the interaction of 15 genotypes in 3 environments of locations L1 (Ludhiana)

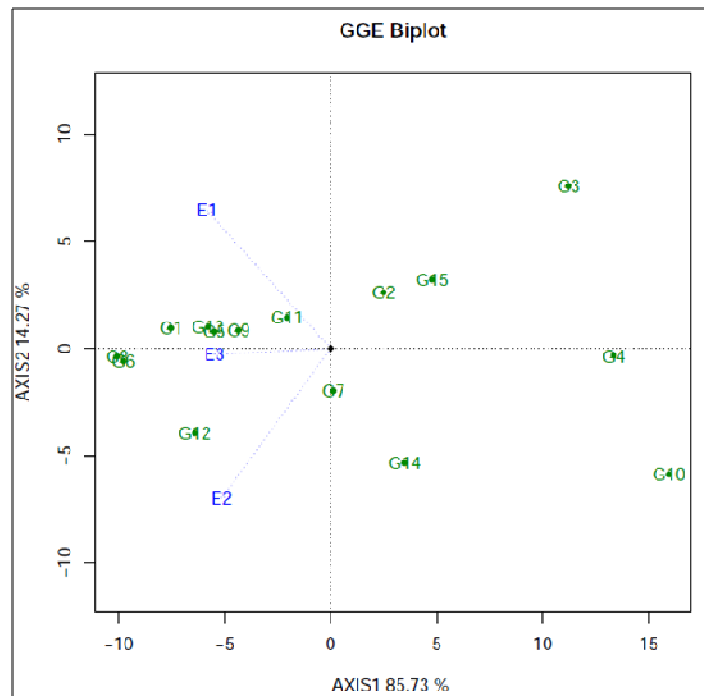


Fig 4.20 (b) GGE Biplot 1 for germination (%) of carrot showing the interaction of 15 genotypes in 3 environments of locations L2 (KVK, Langroya)

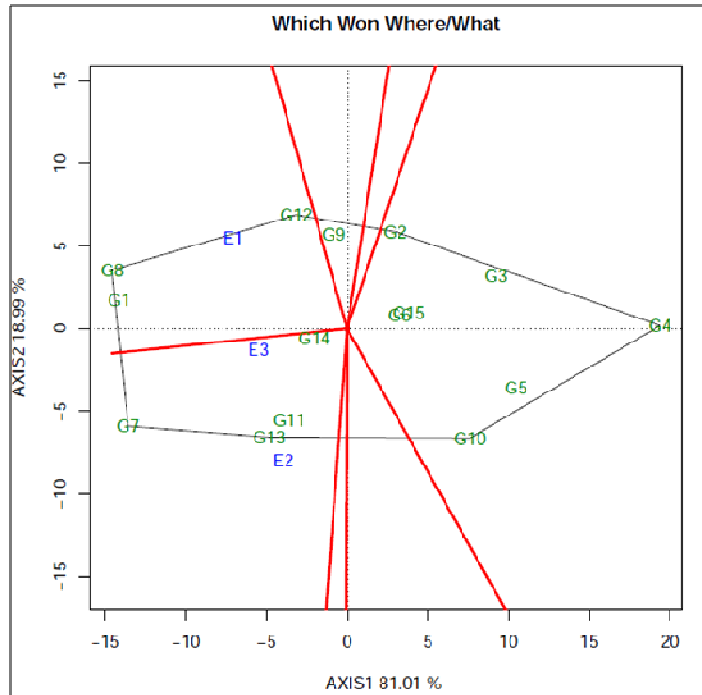


Fig 4.20 (c) Which Won Where GGE Biplot of germination (%) of carrot showing the interaction of 15 genotypes in 3 environments of locations L1 (Ludhiana)

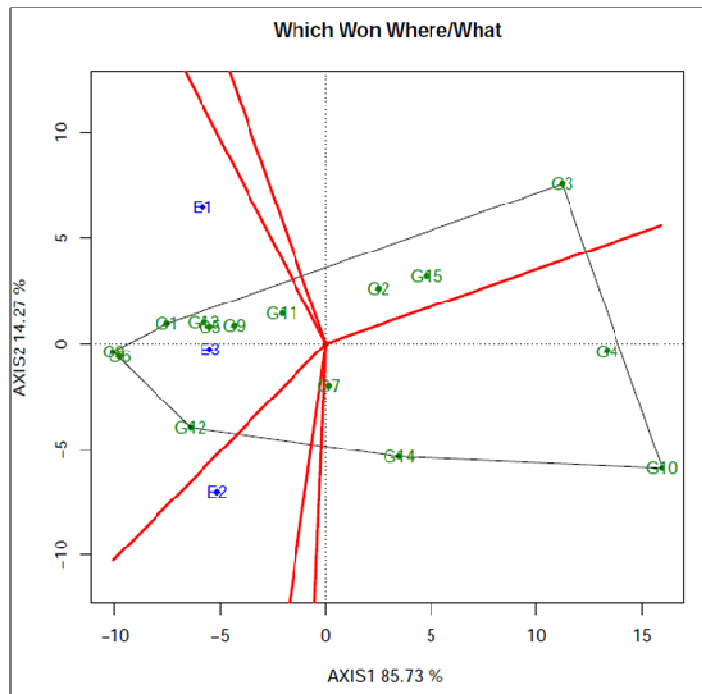


Fig 4.20 (d) Which Won Where GGE Biplot of germination (%) of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-28 (G7) was closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.11 Speed of germination

From both the locations L1 (Ludhiana) and L2 (KVK Langroya), it has been depicted that the speed of germination of carrot was significantly better in L2 (5.76) as compared to L1 (5.04). Date of sowings also had significant effect on speed of germination. D1 (First week on December) showed significantly higher speed of germination which was statistically at par with D2 (First week of January) and significantly better over D3 (First week of February). The speed of germination differed significantly due to genotypes. It ranged from 4.95 to 6.08. Genotype 10 (P-35) showed the maximum (6.08) speed of germination which was statistically at par with genotype 9 (P-29) (5.63) and significantly better over all other genotypes.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for speed of germination was given in Figure 4.21 (a). At location 1 (PAU, Ludhiana), the genotypes P-23 (G6), P-4 (G2), P-18 (G5) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Carrot Nantes (G12), PCO-6 (G11), P-5 (G3), P-28 (G7) had maximum speed of germination exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype and Pusa Meghali (G14), Arka Suraj (G15), were poor performers across the three plantings (three environments).

Fig. 4.21 (b) showed the GGE Biplot 1 performance of 17 genotypes and environment for speed of germination of location 2. The genotypes P-23 (G6), P-18 (G5) and Carrot Nantes (G12) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, P-41 (G9), PCO-6 (G11) and P-16 (G4) had maximum number of seeds per plant exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype P-4 (G2) and P-29 (G8) were poor performers across the three plantings (three environments) due to minimum speed of germination.

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.21 (c) of GGE Biplot. PCO-4 (G10), P-3 (G1), Carrot Early Nantes (G13), Arka Suraj (G15), P-29 (G8) and P-41 (G9) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega

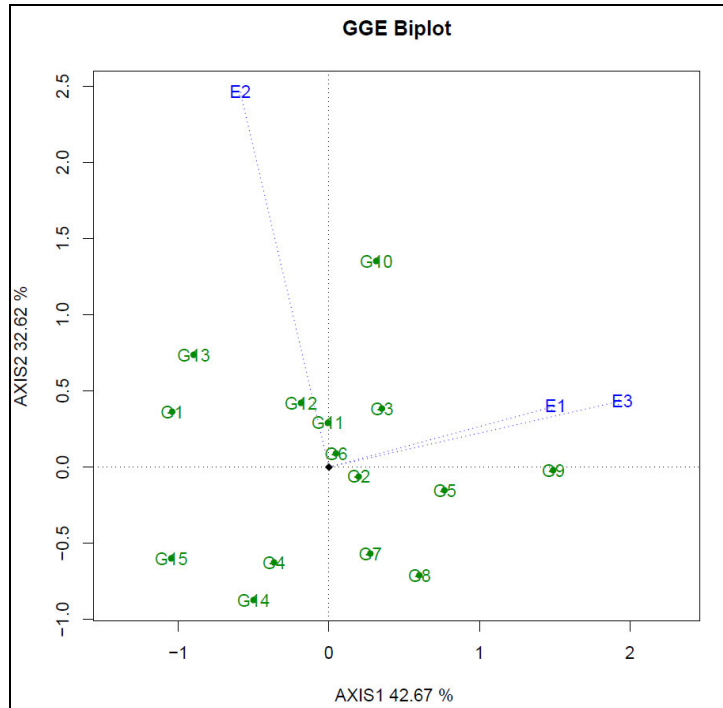


Fig 4.21 (a) GGE Biplot 1 for speed of germination of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

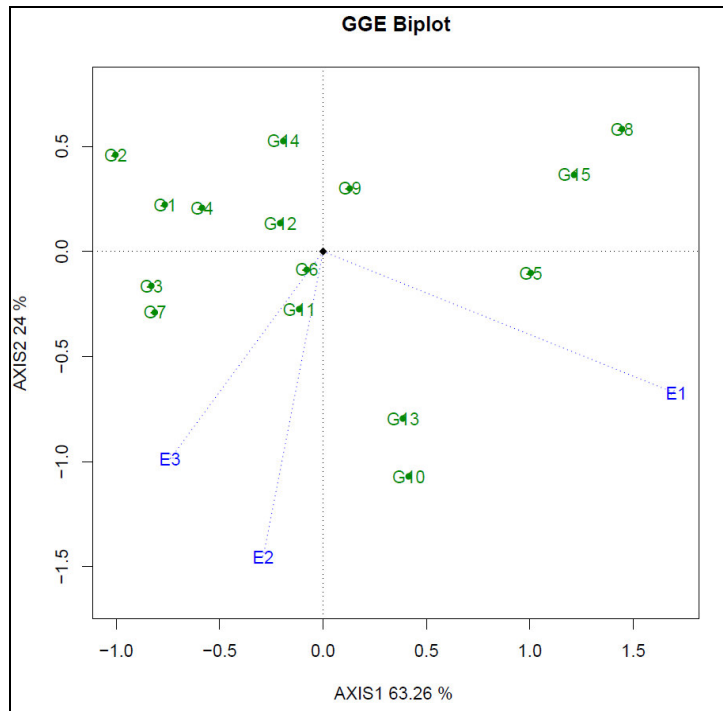


Fig 4.21 (b) GGE Biplot 1 for speed of germination of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

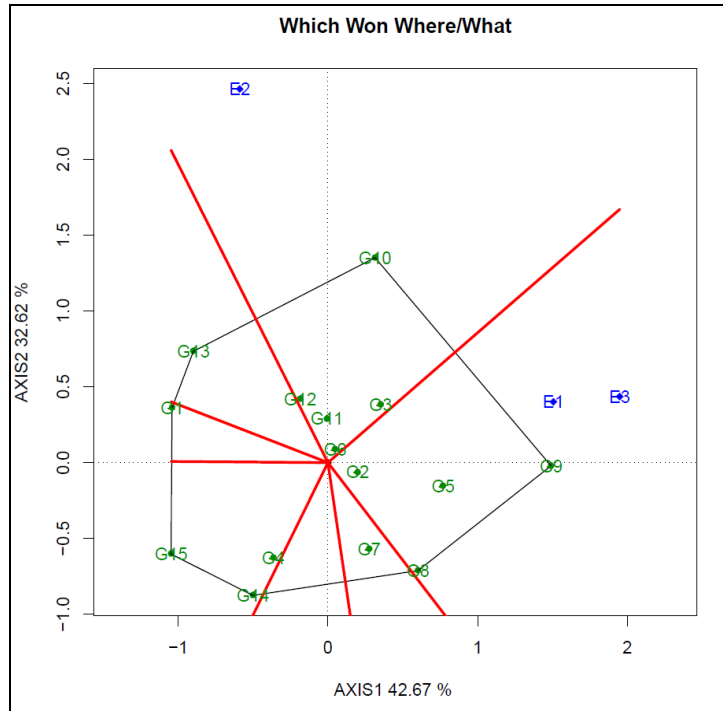


Fig 4.21 (c) Which Won Where GGE Biplot for speed of germination of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

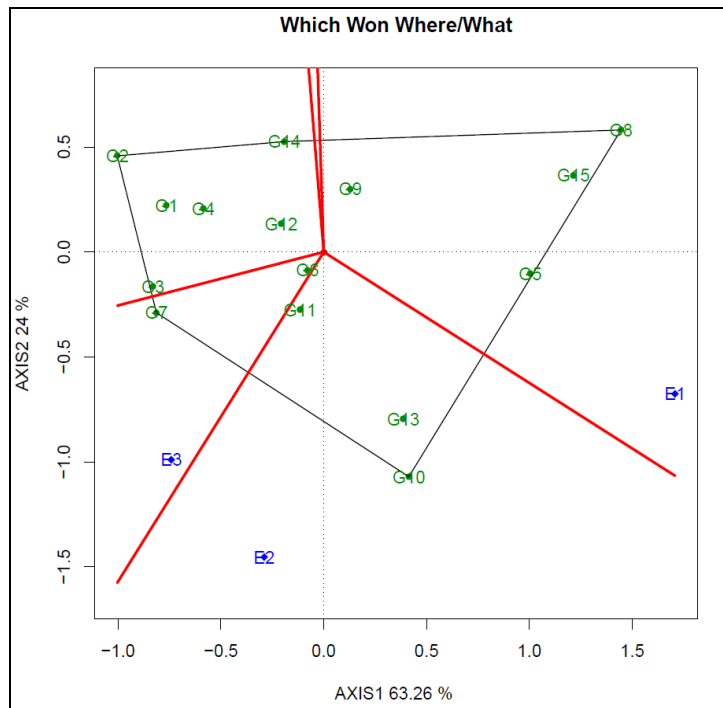


Fig 4.21 (d) Which Won Where GGE Biplot for speed of germination of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

environments were distinguished. The genotypes P-4 (G2), P-23 (G6) and PCO-6 (G11) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.21 (d) of GGE Biplot. The genotypes P-4 (G2), P-28 (G7), PCO-4 (G10), P-18 (G5), P-29 (G8) results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-23 (G6), PCO-6 (G11) and Carrot Nantes(G12) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.12 Seedling length (cm)

Among both the locations L1 (Ludhiana) and L2 (KVK Langroya), the seedling length of carrot was significantly better in L2 (14.08cm) as compared to L1 (12.86 cm). Date of sowings also had significant effect on seedling length. D2 (First week on January) showed significantly higher seedling length which was statistically at par with D1 (First week of December) and significantly better over D3 (First week of February). The seedling length differed significantly due to genotypes. It ranged from 12.61 to 14.01 cm Genotype 6 (P-18) showed the maximum (14.01 cm) seedling length which was statistically at par with genotype 5 (P-17) (13.51 cm) and significantly better over all other genotypes as shown in table 4.8.

GGE Biplot 1

GGE Biplot 1 performance of genotypes and environments for seedling length was given in Figure 4.22 (a). At location 1 (PAU, Ludhiana), the genotypes P-41 (G9) and P-23 (G6) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, PCO-4 (G10) and P-16 (G4) had maximum seedling length exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype and P-18 (G5) were poor performers across the three plantings (three environments).

Fig. 4.22 (b) showed the GGE Biplot 1 performance of 17 genotypes and environment for seedling length of location 2. The genotypes Carrot Nantes (G12), P-41 (G9), P-16 (G4) and Pusa Meghali (G14) showed stable performance as they had lower coordination on IPCA I axis and thus contributed least towards the G×E interaction. The genotypes namely, Arka Suraj (G15) and P-3 (G1) had maximum seedling length exhibiting adaptation to all three environments and therefore categorized as generalists. The genotype and P-23 (G6) were poor performers across the three plantings (three environments).

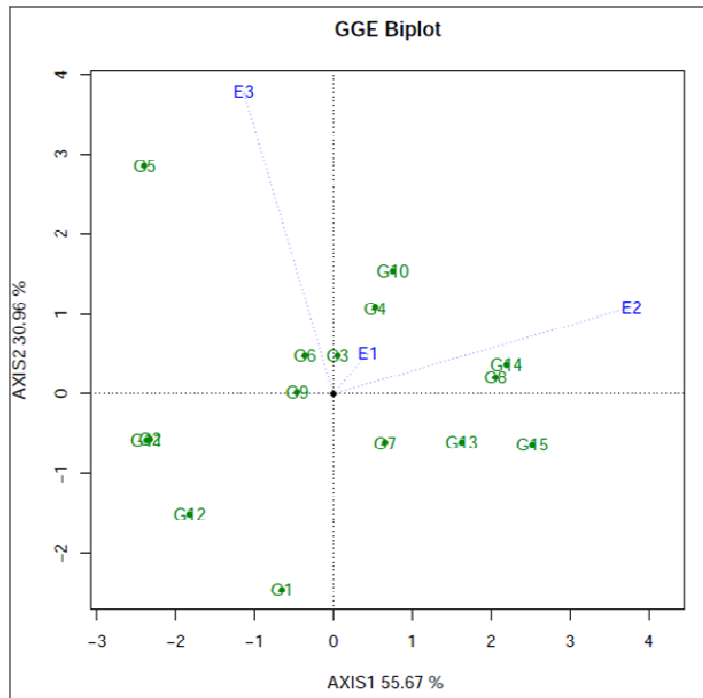


Fig 4.22 (a) GGE Biplot 1 for seedling length (cm) of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

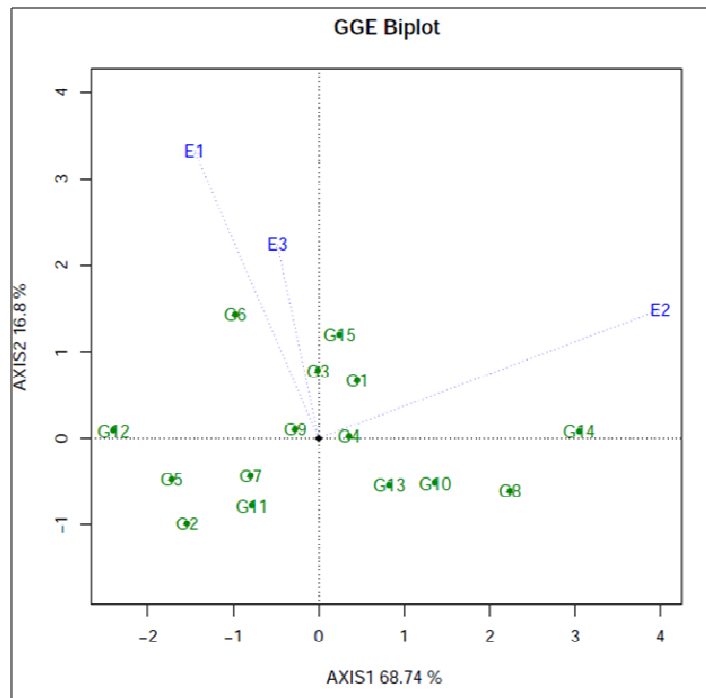


Fig 4.22 (b) GGE Biplot 1 for seedling length (cm) of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

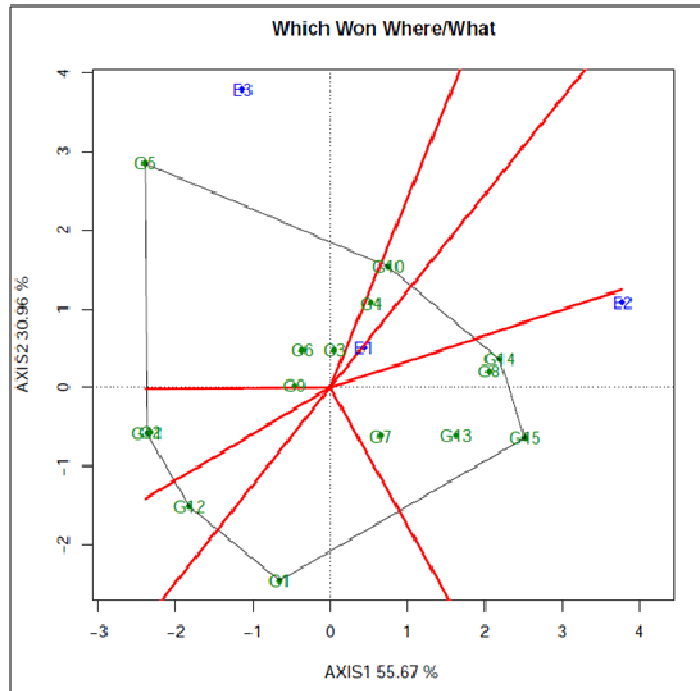


Fig 4.22 (c) Which Won Where GGE Biplot for seedling length (cm) of carrot showing the interaction of 15 genotypes in 3 environments of location L1 (Ludhiana)

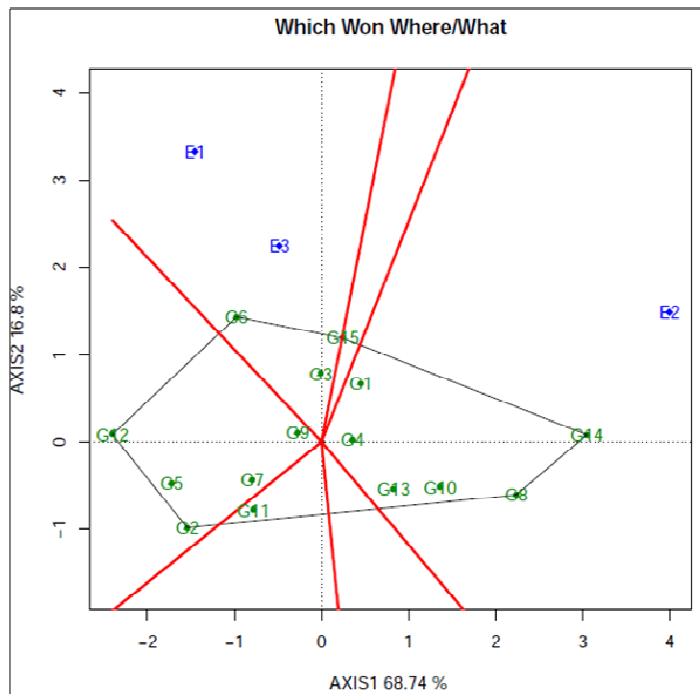


Fig 4.22 (d) Which Won Where GGE Biplot for seedling length (cm) of carrot showing the interaction of 15 genotypes in 3 environments of location L2 (KVK, Langroya)

GGE Biplot 2

The stability of genotypes and environments (sowings), as well as specific G×E interaction at location 1 is represented in Figure 4.22 (c) of GGE Biplot. P-18 (G5), PCO-4 (G10), Pusa Meghali (G14), Arka Suraj (G15), P-3 (G1) and Carrot Nantes (G12) connects the polygon and had highest vectors in their particular direction from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-41 (G9) and P-29 (G8) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

At location 2, the stability of genotypes and environments (sowings), as well as specific G×E interaction at two locations is represented in Figure 4.22 (d) of GGE Biplot. The genotypes P-23 (G6), Pusa Meghali (G14), P-29 (G8), P-4 (G2) and Carrot Nantes (G12) results in polygon and had highest vectors in their particular direction) from biplot point of origin, were extreme genotypes and produced greatest contribution to G×E interaction. The other genotypes had smaller vector, which were contained within the polygon, means they were less sensitive to environmental interactions in each sector. For the present character, six mega environments were distinguished. The genotypes P-41 (G9) and P-16 (G4) were closest to the origin (near to zero of both IPCA axis) considered highly stable genotypes in all the environments.

4.3.13 Vigour index I

From both the locations L1 (Ludhiana) and L2 (KVK Langroya), the vigour index I of carrot was significantly better in L2 (1084.10) as compared to L1 (927.75). Date of sowings also had significant effect on vigour index I. D2 (First week on January) showed significantly higher vigour index I which was statistically at par with D3 (First week of February) and significantly better over D1 (First week of January). The vigour index I differed significantly due to genotypes. It ranged from 898.24 to 1182.26. Genotype 8 (P-28) showed the maximum (1182.26) vigour index I which was statistically at par with genotype 6 (P-18) (1079.47) and significantly better over all other genotypes.

4.3.14 Vigour index 2

Table 4.8 indicated that both the locations L1 (Ludhiana) and L2 (KVK Langroya), the vigour index 2 of carrot was significantly better in L2 (0.78) as compared to L1 (0.61). Date of sowings also had significant effect on vigour index 2. D2 (First week on December) showed significantly higher vigour index 2 which was statistically at par with D1 (First week of January) and significantly better over D3 (First week of February). The vigour index 2 differed non significantly within genotypes.

CHAPTER -V

SUMMARY

Carrot (*Daucus carota* L.) is a biennial herbaceous species found in Umbelliferae family. Carrot classification is done on the basis of pigmentation in the carrot roots. Carrots were originated from Afghanistan. Asian carrots include purple, yellow and red coloured roots whereas European carrots comprised of orange and white coloured roots. The colour variation in carrot is due to genotypes and prevailing temperature conditions during growth period. Carrot has been widely cultivated since long, but the productivity of carrot is considerably low and there is a scope to increase the production potential of carrot. Two main types of carrot are: Tropical or Asiatic types and Temperate or European types. Both these types of carrot are cultivated in India but for seed production they require different climatic conditions. The Asiatic/tropical varieties produce their seeds freely in the plains without chilling requirement and at 7.2-23.9°C seeds germinates well but temperature below 15°C may result in formation of seed stalks which is suitable for seed production. The temperate/European types need chilling/vernalization of 4-5°C temperature for 40-60 days duration for bolting depending upon the range of temperature. Therefore, their seed production is organized in hilly areas. Seed formation of European carrots takes place at 12.2°-21°C. Seed of European or temperate types which are biennial can be produced only in hilly regions while Asiatic or tropical types set seeds in the plains of India. However, the seed supply from the domestic production is not adequate and growers depend mainly on imported seeds that demand foreign currency and are of questionable sources with respect to germination and susceptibility to diseases. Thus, to improve the production and productivity of carrot domestically, the availability of quality seed is crucial. So, seed production of European carrot is a challenge in plain regions. Therefore, the present study has been formulated to widen the crop improvement programme with the following objectives:

- To identify the most promising genotype of carrot in each environment.
- To identify the best season for seed production of different genotypes of carrot.

The study included two experiments which are conducted on two locations i.e. Research Farm (Director Seeds), Punjab Agricultural University, Ludhiana (L1) and KVK, Langroya, Saheed Bhagat Singh Nagar (L2). Both experiments were conducted at different sowing dates. First experiment contained four dates of sowings viz., First week of September (D1), Last week of September (D2), Second week of October (D3) and First week of November (D4) and 17 genotypes which were evaluated on the basis of morphological and biochemical characters. Second experiment consisted of three dates of transplanting of stecklings i.e. first week of December (D1), first week of January (D2) and first week of February (D3) and seed production potential of 15 genotypes were checked at both locations.

These two experiments were carried with Split Plot Design and each contained 3 replications. Analysis of variance (ANOVA) for both experiments was done by using computer based programme CPCS 1 and GGE Biplot model was used to produce biplot graphs which display the variability of genotypes and G×E interactions.

The results obtained during the course of study are summarized below:

- Plant height was maximum at location 1 (PAU, Ludhiana) when sown in first week of November (D4) and the performance of genotype P-35 (G10), genotype 11 (P-41), genotype 13 (PCO-6) have higher plant height in comparison to other genotypes.
- Shoot weight of genotype 4 (P-16), genotype 5 (P-17), genotype 3 (P-5) was maximum in location 1 (Ludhiana) when these genotypes were sown in first week of November (D4) as compared to other sowing dates.
- Shoot length of genotype 11 (P-41), genotype 10 (P-35) and genotype 2 (P-4) was observed maximum at location 1 (Ludhiana) as compared to location 2 (KVK, Langroya) in fourth date of sowing (First week of November) over other date of sowings.
- Root length was recorded to be maximum at location 2 (KVK, Langroya) in first week of November (D4) when compared within the four date of sowings and genotype 10 (P-35), genotype 9 (P-29) and genotype 16 (Pusa Meghali) performed well for root length than all other genotypes.
- Root weight was maximum at location 2 (KVK, Langroya) as compared to location 1 (PAU, Ludhiana) in date of sowing fourth i.e. first week of November of genotype 14 (Carrot Nantes) and genotype 17 (Arka Suraj).
- Root girth of genotype 14 (Carrot Nantes), genotype 13 (PCO-6) and genotype 15 (Carrot Early Nantes) of location 2 (KVK, Langroya) was better than location 1 (Ludhiana) at fourth sowing date i.e. first week of November.
- Genotype 14 (Carrot Nantes) and genotype 16 (Pusa Meghali) have more core girth than all other genotypes at location 2 (KVK, Langroya) as compared to location 1 (Ludhiana) when sown in first week of November.
- Total root yield (kg/plot) of genotype 14 (Carrot Nantes), genotype 7 (P-23) and genotype 15 (Carrot Early Nantes) was maximum at location 2 (KVK, Langroya) as compared to location 1 (Ludhiana) in first week of November (D4) which resulted as best sowing date than other date of sowings.
- Marketable root yield (kg/plot) was maximum at fourth sowing date i.e. first week of November at location 2 (KVK, Langroya) as compared to location 1 (PAU, Ludhiana) of genotype 14 (Carrot Nantes) and genotype 15 (Carrot Early Nantes).
- Root shoot ratio was maximum of genotype 8 (P-28), genotype 17 (Arka Suraj), genotype 10 (P-35) and genotype 1 (P-3) at location second (KVK, Langroya) in comparison with

location first (Ludhiana) in third sowing date (Second week of October) which was statistically at par with fourth sowing date (First week of November).

- Total soluble solids (° Brix) was higher in second location (KVK, Langroya) of genotype 10 (P-35), genotype 3 (P-5) and genotype 15 (Carrot Early Nantes) in first week of November (D4) in comparison to other date of sowings.
- Sugar content (%) of European carrot genotypes was higher at location 2 (KVK, Langroya) when sown in first week of November (D4) as compared to other sowing dates and genotypes such as G12, G16, G15, G4, G11, G17 showed maximum sugar content than other genotypes.
- In second week of October (D3) and first week of November (D4), genotypes possessed higher amount of carotene content at location 2 (KVK, Langroya) as compared to location 1 (Ludhiana) and genotype 4 (P-16), genotype 10 (P-35) and genotype 11 (P-41) showed best performance for carotene content.
- Number of branches were significantly higher at location 1 (Ludhiana) in second date of sowing (First week of January). Among the genotypes, genotype 14 (Pusa Meghali) showed maximum number of branches which was statistically at par with genotype 1 (P-3).
- Number of secondary umbels was significantly more at second location (KVK, Langroya) in second date of sowing (First week of January). The number of secondary umbels was significantly higher in genotype 15 (Arka Suraj) which was statistically at par with genotype 13, genotype 14.
- Number of tertiary umbels performed well at location 2 (KVK, Langroya) in second date of sowing (First week of January). Genotype 3 (P-5) was the best genotype among the other genotypes which were statistically at par with genotype 12 (Carrot Nantes) and genotype 13 (Carrot Early Nantes).
- Number of seeds per plant was non significant between both the locations but first date of sowing (First week of December) showed highest number of seeds which was significantly maximum over all other sowing dates. Among the genotypes, genotype 10 (PCO-4), genotype 11 (PCO-6), genotype 12 (Carrot Nantes) showed significantly higher number of seeds per plant than other genotypes.
- Seed weight per plant was observed maximum at location 2 (KVK, Langroya) in first date of sowing (First week of December). Seed weight per plant of genotype 11 (PCO-6), genotype 10 (PCO-4), genotype 12 (Carrot Nantes) were significantly higher as compared to other genotypes.
- Seed yield per hectare was significantly higher in location 2 (KVK, Langroya) in first sowing date (First week of December). Genotypes also had significant results with higher

seed yield per hectare in genotype 11 (PCO-6) which was statistically at par with genotype 12 (Carrot Nantes) and genotype 10 (PCO-4).

- At location 2(KVK, Langroya) higher germination (%) was recorded in second date of sowing (First week of January) and genotype 8 (P-29) showed the highest germination (%) among all other genotypes.
- Genotype 6 (P-23) recorded the maximum seedling length at location 2 (KVK, Langroya) in second date of sowing (first week of January) which was statistically at par with first date of sowing (first week of December).
- Vigour index I and II was maximum of P-29 and Arka Suraj genotype at location second (KVK, Langroya) as compared to first location in second sowing date i.e. first week of January.

Conclusion

The results obtained from present investigation conclude that European carrot genotypes performed well at both locations but results from KVK, Langroya was better. October and November sown genotypes showed better morphological and biochemical traits. Carrot Nantes, P-35 and P-41 were best genotypes in terms of morphological and biochemical traits. All the genotypes gave good seed production potential in both locations, however seed production at Langroya was comparatively better. December and January transplanted seedlings performed better in seed yield and quality. Among the genotypes, Carrot Nantes, PCO-6, PCO-4 and P-29 have higher seed potential.

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