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RESEARCH ARTICLE

Agro-morphometric Diversity Analysis in Carrot Germplasm from Indian Genebank

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Carrot is a nutrient rich and commercially important root vegetable in India. A study was undertaken in *rabi* seasons of 2015-16 and 2016-17 to assess the agro-morphological diversity in 100 accessions collected from different regions of India and from other countries. Wide variation was observed in accessions for qualitative (root and core colour) and quantitative (plant length, root length and length, shoulder, root, core size, number of leaves per plant, total plant weight root yield etc.) traits. Maximum accessions had red and mixture of light red (45) to light purple roots (38). Only orange accessions had uniformity in root shape and colour. Wide variation was observed in root length (13.6-25.6 cm) and shoot length (25.0 - 88.3 cm). The study revealed wide variation in carrot germplasm maintained by Indian genebank, however, intra-population variation needs to be fixed before use in breeding.

Key Words: Diversity analysis, Germplasm, Morphometric traits, National Genebank, Tropical carrot

Introduction

Carrot (*Daucus carota* L.) is one of the most important and nutritious vegetables grown in the world. Its production has increased to 42.8 million tons from 1.15 million ha area (FAOSTAT, 2017) with average annual growth rate is 4.26%. The primitive purple and yellow carrots were source for evolution of modern-day edible carrots (Bradeen and Simon, 2007; Simon *et al*., 2008) which have diverse colours *i.e.* red (lycopene), orange (β-carotene), black (anthocyanin), white (lutein) and yellow (xanthophylls). Carrot is typically of two types, namely (i) Asiatic/tropical type which form edible roots and produce seeds profusely in tropical and sub-tropical climate without vernalization requirement and (ii) the temperate or European type which forms good quality roots in cool months in sub-tropical environment, but needs vernalization to initiate bolting (initiation of flower stalk). In India, tropical carrots are preferred for juice, pudding (*gajar halwa*), vegetable and fresh salad, pickle purposes (Kushlaf and Kalia, 2012) but remain available in winter season only while European/ temperate type are available throughout the year due to their storability. India has good extent of diversity in carrot germplasm as reported by Saha *et al*. (2016). However, they used only 38 tropical carrot inbred lines, whereas more than 100 collections have been reported by ICAR-National Bureau of Plant Genetic Resources (NBPGR), New Delhi. Hence, evaluation of germplasm for economically important traits was prerequisite for breeding use.

Agro-morphometric traits are functional representation of gene(s) and environment interaction and they are simple, inexpensive and easily observable. Such traits have been effectively used in understanding diversity in *Capsicum* from Peninsula of Baja California (Murillo-Amador *et al*., 2016), mulberry from Giardinello, Sicily, Italy (Lo Bianco *et al*., 2018), maize from different regions (Yousaf *et al*., 2007) and diverse plant species in northern China (Meng *et al*., 2009). Morphological description of inter- and intra-accession in a germplasm helps in deciding the use of molecular markers, particularly in carrot which is a highly cross-pollinated crop and has high level of inbreeding depression. Diversity in carrot germplasm was also reported from Turkey (Balakaya *et al*., 2005), United States of America (Luby *et al*., 2016) and China (Ma *et al*., 2016). In India, 27 genotypes of temperate carrot were evaluated for economic traits in North Western Himalayas (Kumar *et al*., 2009), 32 genotypes of temperate carrot (Saha *et al*., 2015) and 38 genotypes

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of tropical carrot (Saha *et al*., 2016) for morphological traits and heat tolerance, respectively in Delhi. Amin *et al*. (2010) reported morphological variation in 48 genotypes (both temperate and tropical types) in Punjab, India. However, these studies were only aimed to investigate the advance genotypes available with respective centres and none of them targeted germplasm available with national genebanks such as NBPGR, New Delhi. The present investigation was aimed to characterize the carrot germplasm available at National Genebank for agro-morphometric traits.

Materials and Methods

A set of 108 germplasm from Indian Council of Agricultural Research (ICAR)-National Bureau of Plant Genetic Resources (NBPGR), New Delhi was received for characterization based on morphological traits. It comprised of traditional cultivars/folk varieties (17), released varieties (16), Elite lines (11), landraces (6), registered germplasm/genetic stock (6), breeding lines (5), parental lines (2) and others (45). These were predominantly collected from different parts of India while three were exotic lines. The checks used were four open-pollinated varieties, namely Pusa Rudhira (tropical, red colour, self core and main season), Pusa Vrishti (tropical, light red colour, self core and heat tolerant variety), Pusa Asita (tropical, black colour, self core and main season) and Pusa Meghali (tropical, light orange colour, self core and main season).

The germplasm was evaluated at Division of Vegetable Science, ICAR- IARI, New Delhi in *rabi* seasons of 2015-16 and 2016-17. The trials were conducted in randomized block design with two replications. The crop was raised on ridges (15 cm height, 20 cm width) made 30 cm apart in paired row system in plots of 3 × 1 m size (3 sq m). Sowing was done at 5 cm distance and maintained a spacing of 10 cm by thinning after 30 days of sowing and recommended package of practices were followed during crop growth.

The observations for agro-morphometric traits namely plant height (cm), shoot length (cm), total plant weight (g), number of leaves per plant, root length (cm), shoulder diameter (cm), root diameter (mm), core diameter (mm), cortex diameter (cm), individual root weight (g) and shoot weight (g) were recorded from five random plants using standard rulers and electronic balance. Marketable root yield was derived from plot yield. The root to gross plant weight ratio and root to shoot weight ratio were derived from the component traits. Number of marketable roots were counted per plot and percentage of the same was calculated by using formula as, marketable roots (%) = (Number of marketable roots per plot/Total number of roots per plot) × 100.

The statistical analysis of the data was performed using R Software for principal component analysis, correlation coefficient, basic statistics creating heatmap and K-means analysis while DARWIN 6.0 version was used for diversity analysis.

Results and Discussion

In total, 101 accessions germinated and one accession IC-330367 did not form carrot type roots and bolted directly, which was not included in present study. Hence, the current experiment and analysis has been carried out using 100 accessions along with four commercial checks. The root and core colours of investigated accessions are given in Table 1. These 100 accessions were grouped on the basis of root skin colour as black (04), orange (14), mixture of light purple, white, pale or red (38) and light to dark red (44).

Plant Traits

The observations on plant traits in germplasm evaluated are presented in Table 2. Whole plant height (root + shoot length) ranged from 41.4 to 103.7 cm, the highest in IC0347795 followed by IC0537770, IC0361562-X, IC0371696, IC0570071 and EC0171367 while it was minimum in IC526888. Accessions showed wide variation for root length which was ranged from 13.5 (IC0606225) to 25.5 cm (IC0598342) and none of the accessions had root length more than commercial variety Pusa Rudhira (25.6 cm) and Pusa Asita (31.4 cm) while IC0598342 had better than Pusa Meghali (25.3 cm). Pusa Vrishti is a heat tolerant open pollinated variety of tropical red carrot and 50 accessions had root length greater than this indicating scope for screening germplasm in early group for longer roots and other desirable traits. Shoot length was prominent over the check varieties in almost all the accessions and highest was observed in IC0347795 (88.3 cm) followed by IC0537770 (82.1 cm), IC0144374 (79.2 cm) and EC0171374 (77.84 cm). However, shoot length was minimum in IC0143948 (23.5 cm) and IC0121429 (22.7 cm). The shoot length should be less so that plant can divert more photosynthates towards root development.

An optimum number of leaves are desirable because excessively low or high affect root yield. Broader

Table 1. Observations on root and core colours of carrot germplasm

Accessions	Root colour	Core colour
EC0171367	Purple, red, white	Light purple
EC0171374	Light purple, white, red	Light purple, white
EC0368401	Purple, white, red	Red
IC0121429	Orange	Pale
IC0143948	White, light purple	Pale
IC0143949	Purple, red, white	Purple
IC0143950	Purple, orange, white	Purple, pale, light red
IC0143951	Purple	Purple, pale, red
IC0143952	Purple, light purple, white	Red, pale
IC0143953	Purple, white, red	Pale
IC0143954	Red, purple	Purple, pale
IC0143955	Red, purple, white	Pale, light red pale
IC0143956	Purple, white, light red, purple	Light purple, pale
IC0143957	Red, purple, white	Light purple
IC0143958	Red, purple	Medium purple, pale
IC0144373	Red, white, purple	Light red
IC0144374	Purple, light, red	Pale
IC0144375	White, red	Medium purple
IC0144376	White, purple, red	Purple
IC0144377	Light purple	Purple pale
IC0144378	White, red	Red
IC0144379	White, red	Light purple, pale, light red
IC0144380	White, red	Purple white
IC0144381	White, red	Red
IC0144382	Red, purple	Pale
IC0144383	Purple	Medium red purple
IC0144384	Red, light purple	Red, pale
IC0146714	Purple, white, red	Red
IC0146715	White, purple, red	Red
IC0265265	Red	Red
IC0284904	Red, white	Red
IC0284927	Orange	Orange
IC0312821	Red	Red
IC0312835	Red	Red
IC0312919	Red, white	Light purple
IC0312928	Red, yellow	Light red
IC0312942	Red	Light red
IC0312956	Red	Light red
IC0312995	Purple, white	Pale
IC0313041	Red	Pale
IC0318887	Red	Red, light red
IC0325192	Red, light	Red
IC0325192-X	Purple, white	Pale
IC0325193	Red	Red
IC0325194	Red, light purple	Light purple
IC0325197	Medium red	Pale
IC0331877	Medium red	Light purple, white
IC0331885	Red	Light red
IC0331978	Black	Pale, light purple
IC0339571	Black	Light purple, pale
IC0339572	Orange	Orange
IC0361562	Orange	Orange
IC0361562-X	Purple, white, pale	Pale
IC0369523	Purple, white	Red
IC0371696	Black	Purple, white
IC0374708	Red	Red
IC0399065	Red	Red
IC0399657	Purple	Red
IC03399658	Red	Red
IC0399659	Red	Red
IC0405214	Orange	Orange
IC0411726	Purple, white	Pale
IC0141736	Purple	Light purple
IC0411817	Black	Light purple
IC0470032	Orange	Orange
IC0970062	Orange	Orange
IC0512325	Red	Purple
IC0524226	Red	Light red
IC0537770	Purple, white	Pale
IC0565022	Red	Light purple
IC0565023	Purple	Red
IC 0566229	Orange	Orange
IC0566230	Orange	Orange
IC0570071	Purple, white	Red
IC0570261	Light red	Light red
IC0591033	Red, pale	Pale, red, pale green
IC0593950	Orange	Orange
IC0596514	Red, purple	Purple
IC0598342	Red	Red
IC0598343	Red	Pale
IC0598344	Red	Purple
IC0606225	Purple, white	Pale
IC0607364	Purple, white	Light red, pale green
IC0614611	Red	Light red
IC0614612	Purple	Light purple
IC0312995	Red	Light red
IC0312948	Red, white red	Light red
IC0313048	Red	Light red
IC0342261	Orange	Orange
IC0342291	Red	Light red
IC0342466	Medium red	Light red
IC0347722	Red	Light red
IC0347795	Orange	Orange
IC0347829	Red	Red
IC0347850	Red	Red
IC0429963	Red	Light red
IC432018	Purple	Red
IC433539	Red	Pale
IC526888	Orange	Orange
IC537826	Orange	Orange
Pusa Rudhira (check)	Red	Red
Pusa Vrishti (check)	Red	Red
Pusa Asita (check	Black	Black
Pusa Meghali (check)	Orange	Orange

shoulder, of course is an undesirable trait. It is essential to identify the accessions which have high net assimilation rate and maintain proper growing potential. Ideally, the accessions should have an optimal level of harvest index (a ratio of economic part to total biomass of plant or crop), to ensure efficient partitioning to root part while preserving a sufficient photosynthetic leaf area (Suojala, 2000).

Root Traits

Root shoulder width is important trait for marketing perspective and narrow shoulder is a preferred trait. It ranged from 22.7 to 64.7 mm (Table 2). Similarly, root diameter is a yield trait and it ranged from 17.2 to 41.3 mm. Germplasm also showed variation for core diameter (7.06 - 27.94 mm), smaller core diameter is desirable trait. Total plant weight, which includes both root and shoot portions weight, was highest in IC0325197 (602.5 g/plant) which also had highest values for root weight as well. But, the roots were excessively bulky and undesirable. Other accessions with highest plant weight were IC0325194, IC0312928, IC0399657 and IC0399657. IC0312942 and IC0399659 had individual root weight greater than Pusa Rudhira (165.0 g) while IC0325197 (201.7 g) had higher root weight than Pusa Asita (195.0 g). The root: gross plant weight ratio is important indicator for yield potential and it should be higher. It was highest in IC433539 (0.80) followed by IC0570261 (0.78) and IC0284927 (0.77) while minimum in IC0361562-X (0.21), IC0399065 (0.25) and IC0596514 (0.25). The root: shoot ratio was maximum in IC0361562-X (3.9) followed by IC0399065 (2.94) and IC0596514 (2.85) while it was minimum in IC433539, IC0570261 and C0284927 (<0.3).

Intra-population variation within the accessions was minimal in all the orange root coloured accessions while it was maximum in red and light purple colour groups. The orange color accessions represent germplasm introduced from European countries by public and or private sectors for commercial or immediate breeding use which later on multiplied/refined and resubmitted to Genebank. However, the red and purple colour accessions are predominately collected locally as landraces or farmers varieties which rarely undergone for purification, hence showed wide variation in root and plant traits. Occurrence of light to purple colour roots within the germplasm indicates for existence of sub-groups as also indicated by Ipek *et al*. (2016) within the purple carrot populations in Eregli District of Turkey. Intra-population variation in carrot accessions might be due to highly cross-pollinated nature of the crop which allows out-crossing along with high degree of inbreeding depression which restricts survival of selfed progenies beyond 3-4 generations (Kalia, 2005).

In germplasm, the share of marketable roots is one of the important criteria which determines the yield potential. It was highest in orange coloured accessions

Table 2. Basic statistics of agro-morphometric evaluation of carrot germplasm

Characters	Germplasm accessions				Check varieties				C.D. (p=0.05)	SE(m)	C.V. (%)
	Mean	Minimum	Maximum	Standard deviation	Pusa Rudhira	Pusa Vrishti	Pusa Asita	Pusa Meghali			
Plant height (cm)	77.3	41.4	103.7	13.8	85.0	69.1	87.5	73.1	13.4	4.8	8.8
Root length (cm)	19.6	13.6	25.6	2.8	25.6	19.5	31.4	25.3	5.1	1.8	6.8
Shoot length	57.5	25.0	88.3	14.0	59.4	49.6	56.1	47.8	13.5	4.8	
Shoulder diameter (cm)	41.3	22.7	64.7	9.1	44.5	39.8	58.2	51.7	3	1.1	
Root diameter (mm)	30.9	17.2	41.3	5.7	37.4	34.2	38.7	41.3	11.1	3.9	
Core diameter (mm)	14.9	7.1	27.9	4.9	10.8	12.4	36.8	35.6	10.1	3.6	
Cortex diameter (cm)	16.0	5.4	29.5	5.2	26.6	21.8	9.5	16.2	2.2	0.71	
No. of leaf per plant	11.1	7.0	28.6	3.5	8.5	8.5	27.3	19.4	1.5	0.5	6.5
Total plant weight (g)		79.3	602.5	86.7	310.0			172.7	113.6	40.4	
Individual root weight (g)		41.5	201.7	32.3	165.0			135.0	55.7	19.8	
Avg shoot weight (g)		20.4	400.8	66.3	145.0	64.0		37.7	97.3	34.6	
Root:gross plant weight ratio	0.5	0.2	0.8	0.1	0.5	0.7	0.5	0.8	0.34	0.11	
Root:shoot ratio	1.2	0.2	3.8	0.6	0.9	0.4	0.8	0.3	3.36	1.2	
Marketable roots (%)	40.6	21.0	73.0	13.4	71.0	58.0	67.0	67.0	-	-	-
Root yield (t/ha)	10.2	4.2	24.2	4.1	29.3	20.8	32.7	23.9	13.4	4.8	6.7

and maximum was observed in IC0361562 and IC537826 (73.0%) followed by IC0284927 (72%). In 96 accessions, it was less than the commercial variety Pusa Rudhira (71.0%) and 84 accessions had less than Pusa Meghali (62.0%) and Pusa Vrishti (58.0%).

Root Yield

The yield potential in the germplasm ranged from 4.2 to 24.2 t/ha, the highest was in IC0325192-X and minimum in IC0374708 (Table 2). Two accessions, namely IC0325192 and IC0361562 outperformed Pusa Vrishti (20.0 t/ha) and Pusa Meghali (23.9 t/ha) for root yield. Most of the higher yielding accessions were of orange colour European carrot because they had high level of uniform marketable roots and low share of unmarketable roots.

Variation in accessions for foliage and root traits appears to be in the line of earlier reports of Hole (1996) who stated that the genotype is the primarily responsible factor for difference in distribution of dry matter between shoot and storage root. The tropical type accessions have less root:shoot ratio compared to European type, which could be due to their genetic makeup to adapt to higher temperature conditions and also that the high temperature is more favourable for shoot growth than for storage root growth (Hole, 1996).

Cluster Analysis

The unweighted pair group method with arithmetic mean (UPGMA) method-based clustering of germplasm accessions using 15 morphometric observations revealed six main clusters and one accession IC0325197 was not part of any of these clusters (Fig. 1). Most of the orange coloured accessions (12) were grouped into a single cluster while purple coloured accessions were distributed across the clusters. The purple and red coloured accessions are part of tropical carrot while orange carrot mainly represents European type. The root and plant traits are distinct in both groups, hence they showed clear grouping pattern. Cluster-1 had nine accessions, cluster-2 had 16 and 12 of them were orange type, cluster-3 had 30 accessions all of which were red to light purple except one purple root accession IC0371696. Cluster-4 had only six accessions, three of which were orange type and one purple root type. Cluster-5 was represented by eight accessions and all of them were grouped in red or light purple category. In cluster-6, there were two sub-clusters each having 11 and 10 accessions. In cluster-7, 13 accessions were of

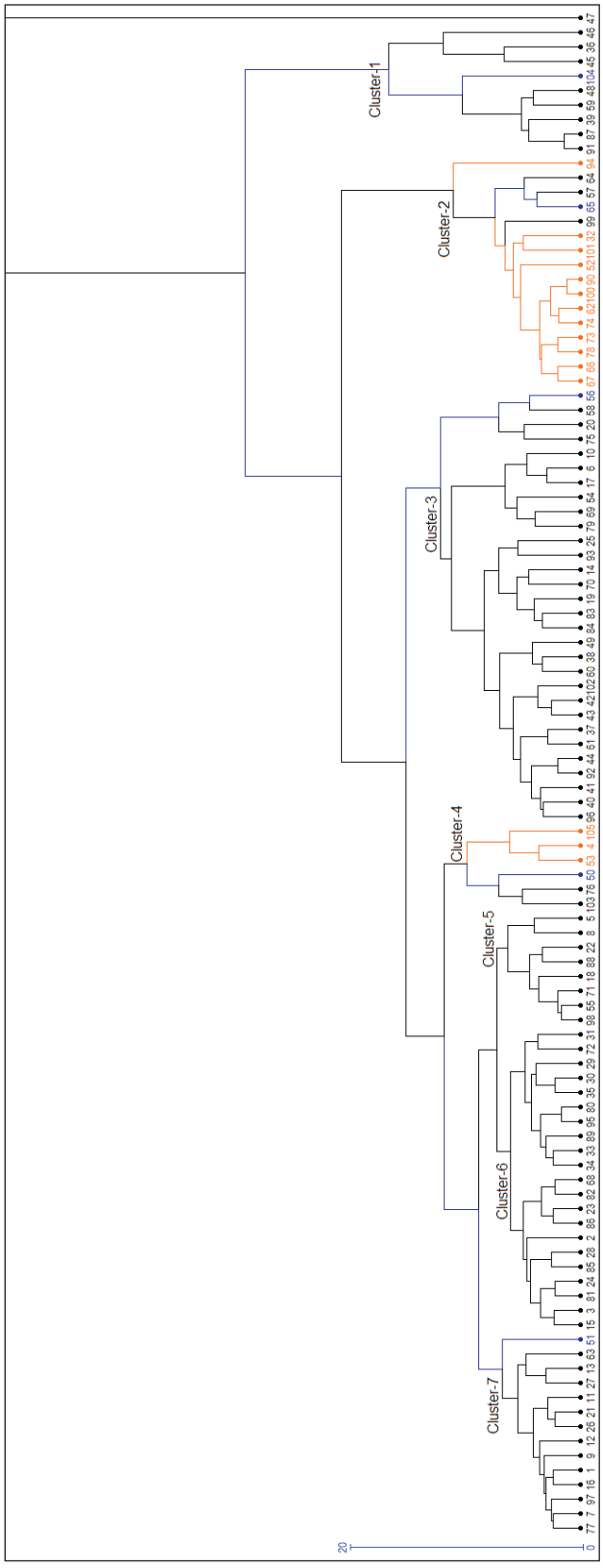

Fig. 1. Hierarchical clustering of carrot germplasm by UPGMA method using 15 morphometric traits (Details of 1-104 are given in Table 1)

red and light purple colour while accession IC0339571 was of purple root colour.

Correlation Analysis

The correlation analysis of 15 morphological (observed and calculated) traits showed significant level of association between plant and root traits (Table 3). It was significantly high between shoot length and plant length (r=0.951), total plant weight (r=0.386) and shoot weight (r=0.394). Root length had negative correlation with shoot length (r= - 0.179) but positively correlated with shoulder diameter (r=0.325), core diameter (r=0.196) and number of leaves per plant (r=0.316). Root diameter was positively correlated with root length (0.274), root weight (r=0.610) and root yield (r=0.237). Per cent marketable roots and root yield was significantly correlated with root yield (r=0.644). Number of leaves per plant was negatively correlated with plant height shoot length, but positively correlated with root length, root shoulder diameter, and root diameter. Hence, breeding for a smaller number of leaves may affect root yield which was also positively correlated.

The morphological variation in the carrot accessions appears to be due to their ancestry because all the accessions were of domesticated carrots which have two groups, the Eastern/Asiatic (var. *altorubens*) and Western (var. *sativus*) groups, and these are genetically distinct (Clotault *et al.*, 2010; Baranski *et al.*, 2012; Iorizzo *et al.*, 2013). The Asiatic types have anthocyanin-pigmented roots and are generally purple, red/pink or orange/yellow in colour and plants are often prone to early flowering and bolt easily. The center of diversity for this group is the Himalayan-Hindu Kush region (Stolarczyk and Janick, 2011). They suggested that the Western sub-group evolved slightly later and are characterized by carotenoid-pigmented roots that are orange, yellow or occasionally red or white in color. Orange carrots were selected from yellow cultivars as indicated by genetic analyses performed by Shim and Jorgensen (2000) and Iorizzo *et al*. (2013). Orange carrot roots require extended exposure to cold temperatures in order to produce flowers and are, thus, adapted to cooler climates (Atherton *et al*., 1990).

Saha *et al*. (2016) also attempted cluster analysis by UPGMA method using 38 inbred lines of tropical carrot with four quantitative traits. They grouped the genotypes into two clusters with 35 and 3 inbreds with maximum distance of 76.67. Amin *et al*. (2010) performed diversity analysis in carrot and reported a wide range of D^2 values (7.71 to 727.17) observed in 48 carrot germplasm, the lowest in IPC-122 and CA-05-01, whereas the upper end is the D^2 between CCA-05-01 and Nantes. The 48 genotypes were grouped into 14 clusters and the pattern of clustering of genotypes is independent of their place of collection or development. They concluded that selection based on weight of marketable roots per plot, root weight, shoot weight per plant and per cent marketable roots would be more efficient for the improvement of better-quality roots in carrot crop. Ibanez *et al*. (2014) performed multivariate analysis of morphological diversity and clearly differentiated two accessions, however, the results

Table 3. Pearson correlation matrix of carrot germplasm

	Plant height (cm)	Root length (cm)	Shoot length	Shoulder diameter (cm)	Root diameter (mm)	Core diameter (mm)	Cortex diameter (cm)	No. of leaf per plant	Total plant weight (g)	Individual root weight (g)	Avg shoot weight (g)	Root: Gross plant weight ratio	Root: shoot ratio	Market-able roots (%)
Root length (cm)	0.043^{NS}													
Shoot length (cm)	0.951^{**}	-0.179^{NS}												
Shoulder diameter (mm)	0.233^{*}	0.325^{**}	0.142^{NS}											
Root diameter (mm)	0.274^{**}	0.296^{**}	0.191^{NS}	0.761^{**}										
Core diameter (mm)	0.211^{*}	0.196^{*}	0.109^{NS}	0.572^{**}	0.533^{**}									
Cortex diameter (mm)	0.078^{NS}	0.133^{NS}	0.073^{NS}	0.267^{**}	0.576^{**}	-0.363^{**}								
No. of leaf per plant	-0.050^{NS}	0.316^{**}	-0.159^{NS}	0.441^{**}	0.417^{**}	0.526^{**}	-0.010^{NS}							
Total plant weight (g)	0.386^{**}	0.230^{*}	0.279^{**}	0.585^{**}	0.610^{**}	0.535^{**}	0.106^{NS}	0.522^{**}						
Root weight (g)	0.221^{*}	0.229^{*}	0.110^{NS}	0.449^{**}	0.610^{**}	0.464^{**}	0.226^{*}	0.450^{**}	0.733^{**}					
Shoot weight (g)	0.394^{**}	0.184^{NS}	0.310^{**}	0.537^{**}	0.487^{**}	0.464^{**}	0.022^{NS}	0.455^{**}	0.937^{**}	0.449^{**}				
Root: plant weight ratio	-0.405^{**}	-0.149^{NS}	-0.371^{**}	-0.377^{**}	-0.208^{*}	-0.256^{**}	0.095^{NS}	-0.215^{*}	-0.541^{**}	0.108^{NS}	-0.766^{**}			
Root:shoot ratio	0.373^{**}	0.139^{NS}	0.334^{**}	0.340^{**}	0.188^{NS}	0.220^{*}	-0.064^{NS}	0.191^{NS}	0.481^{**}	-0.190^{NS}	0.730^{**}	-0.929^{**}		
Marketable roots (%)	-0.334^{**}	0.011^{NS}	-0.358^{**}	-0.179^{NS}	-0.125^{NS}	-0.186^{NS}	0.122^{NS}	-0.010^{NS}	-0.320^{**}	-0.036^{NS}	-0.402^{**}	0.550^{**}	-0.430^{**}	
Root yield (t/ha)	-0.010^{NS}	0.236^{*}	-0.135^{NS}	0.237^{*}	0.389^{**}	0.265^{**}	0.247^{*}	0.345^{**}	0.311^{**}	0.700^{**}	0.049^{NS}	0.412^{**}	-0.391^{**}	0.644^{**}

*, ** Significance at 1 and 5%, respectively. NS- Non-significant.

were not in line with molecular diversity. Baranski *et al*. (2012) reported higher morphological and genetic diversity in Asian genepool than Western type accessions by using 17 and 61 accessions, respectively. Variation within accessions could be due to allelic variation among plants populations as earlier reported by Maksylewicz and Baranski (2013) while studying Intra-population genetic diversity of cultivated carrot from continental Asia, Europe, Japan and USA. They found that allelic richness and variability in landraces was higher than F_1 hybrids and open-pollinated cultivars. Luby *et al*. (2016) investigated 140 accessions in United States of America carrot germplasm and reported that the cultivated carrot germplasm in the USA forms an unstructured population and their findings suggested that the genetic diversity present in carrot cultivars have freedom to operate and is potentially large enough to support carrot breeding efforts in most market classes given present levels of intellectual property protection.

Conclusion

Observations on agro-morphological diversity in carrot accessions conserved in National Genebank highlighted that (i) it has diverse root colour groups i.e. red, light to dark purple, pale to light yellow and orange, (ii) except orange colour accessions, most of others had intra-population variation for root colour and root morphometric traits which was predominant in purple colour accessions, (iii) orange colour accessions showed uniformity in root traits, however, they are of temperate type and did not flower in Delhi condition (because of vernalization requirement) and (iv) none of the accession outperformed commercial varieties except for one or two traits indicating rare possibility of immediate commercial use. The present study revealed significant variation in carrot germplasm at agro-morphological level, however, we suggest for use of molecular tools in assessing the diversity and characterize the accessions after reinforcing homozygosity by attempting selfing for 3-4 generations.

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