Journal of Applied Horticulture, 23(3): 338-343, 2021
https://doi.org/10.37855/jah.2021.v23i03.61
Journal of Applied Horticulture
ISSN: 0972-1045

Variation in tropical and temperate carrot (*Daucus carota* var. *sativa* L.) genotypes

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Abstract

Widespread genetic variation occurs across carrot germplasm, and the assessment of variability provides an important foundation to take advantage of that variation for future carrot improvement. The present investigation was carried out to study the variability, heritability and genetic gain for nineteen traits in carrot. Genotypes PC-161, PC-15, PC-173 (tropical), PCO-30, PCO-5, PCO-7, PCP-2, PCP-1 and PCP-17B (temperate) were found to be superior with respect to highest total and marketable yield. Magnitude of phenotypic coefficient of variation (PCV) was higher than corresponding genotypic coefficient of variation (GCV) for all the characters which indicated role of environment on the character expression. Quantitative traits like total sugar content (%), carotene content (mg/100g), anthocyanin content (mg/100g) and lycopene content (mg/100g) had higher values of GCV, heritability and genetic gain and were found most important traits for applying selection in carrot for crop improvement.

Key words: Carrot genotypes, mean, PCV, GCV, heritability, genetic advance

Introduction

Carrot is a globally important crop that originated in Central Asia (Iorizzo *et al.,* 2013). Cultivated carrot ($2n = 2x = 18$), is among the top 10 most produced vegetable crops globally. Carrot crop yields and production area have risen significantly in the last 50 years, with an especially sharp rise in Asian production (Simon, 2019). The optimum temperature is 7.2.-23.9 °C for germination and 18.3-23.9 °C for growth. The best root colour develops at 15-20 °C (Anonymous, 2021). Asiatic or tropical varieties produce seeds in plains, do not require low temperature for flowering and have red coloured roots while European or Temperate types produces seeds in hills, requires 4.8-10°C chilling temperature for flowering which resulting in its cultivation to hills and have medium and orange coloured roots.

Carrot was first domesticated in Afghanistan, considered to be the primary center of diversity, further it spread over the Mediterranean, Europe and Asia, with Turkey accepted as a second center of diversity (Stolarczyk and Janick, 2011). Carrot is an important source of natural antioxidants and used as cooked, salad, processed product etc. Major carrot growing countries in the world are China, Russia, and United State of America, Uzbekistan and Poland (FAO, 2018). During 2016-17 in India, area under carrot crop was 88 thousand ha and production was 14.46 lakh tonnes (Anonymous, 2017). Major carrot growing states in India are Haryana, Tamil Nadu, Punjab, Karnataka, Uttar Pradesh and Assam (Saxena *et al*., 2016).

Global populations are expected to continue to rise, creating more challenges since future global climates are projected to be hotter, threatening crop production and consequently food security (Wheeler and Braun, 2013). To provide a context for considering approaches that may be used to improve carrot production to meet these future challenges, there is need for development of new varieties and hybrids with high productivity and resistant to biotic and abiotic factors (Hochholdinger and Baldauf, 2018). The critical assessment of nature and magnitude of variability in the germplasm stock is one of the important pre-requisites for formulating effective breeding programme (Janaki *et al.,* 2015).

Greater the variability in a population, greater the chances for effective selection for desirable types (Vavilov, 1951). Phenotypic and genotypic coefficients of variation are useful in detecting amounts of variability present in germplasm (Meghashree *et al.,* 2018). Higher the heritable variation, greater will be the possibility of fixing the characters by selection (Bijma, 2011). Hence, heritability studies are of foremost importance to judge whether the observed variation for a particular character is due to genotype or environment (Kamaluddin and Ahmed, 2011). Estimation of heritability accompanied with genetic advance is generally more useful than heritability alone (Bello *et al.,* 2012). Knowledge of association of various characters provides the basis of selection for yield and its components for crop improvement. Few reports are available on phenotypic variability in carrot (Huasen *et al*., 2007). Keeping in view all this, an attempt was made to study the genetic variability, heritability and genetic advance for various economic characters in the collection of tropical and temperate carrot (*Daucus carota* var. *sativa* L.) genotypes.

Materials and methods

Plant material: The present investigation was carried out at Vegetable farm, Department of Vegetable Science, College of Agriculture, Punjab Agricultural University, Ludhiana. Experimental material consisted of eighty five (85) genotypes comprised of forty nine (49) Asian and thirty six (36) European.

The row and plant spacing was maintained at 67.5 cm and 8 cm, respectively and followed all recommended practices (Anonymous, 2021).

Traits under study: Data were recorded on ten plants randomly taken in each plot. Observations were recorded for nineteen (19) economic characters. The biochemical traits evaluated were Sugar content (%) (Dubois *et al*., 1956), lycopene content (Srivastva and Kumar, 2006), total soluble solids (Rashidi *et al.,* 2010), dry matter content (%), β-carotene (mg/100g), juice yield (mL/kg) and anthocyanin content (mg/100g) (Rabino *et al*., 1977).

Statistical analysis: The phenotypic and genotypic coefficients of variation (PCV and GCV) were estimated as per Burton and DeVane (1953). Heritability in the broad sense and genetic advance (in terms of percentage of mean) were computed according to (Allard, 1960) and Johnson *et al*. (1955), respectively. Different quantitative traits for both years were combined for Analysis of Variance procedures of SAS (SAS institute, 2003).

Results and discussion

Critical assessment of variation for tropical genotypes: Carrot germplasm encompasses a wide range of genetic variability and provides a foundation for better understanding and utilizing that variation for improvement (Simon, 2019). Mean values with range of different traits in Tropical carrot genotypes are shown in Table 1. Few promising genotypes superior to specific traits are: PC-17 (30.8 cm) and PC-161 (30.0 cm) for root length, PC-161 (127.2 g) and PC-173 (126.0 g) for root weight, Pusa Vrishti for root girth (3.4 cm) and flesh thickness (2.56 cm), PC-5 (2.89) for root shoot ratio, PC-161 (9.3 kg/ plot, 9.2 kg/plot) for total and marketable yield. The result is in consonance with Kumar *et al*. (2021) & Thakur and Jamwal (2015) for root length. Ladumor *et al.* (2020) observed that root length varied 22.31 to 23.04 cm. Teli *et al*. (2017) observed large amount of variation in flesh thickness. According to Amin and Singla (2010) the marketable yield ranged from 2.6 to 6.9 kg/plot.

TSS content was maximum in genotype PC-34 and PC-161 (9.7 °Brix), while Pusa Vasuda, PC-172 and PC-173 have maximum total sugar content (5.3 %). Highest carotene content (8.7 mg/100g) was reported in PC-161. Peak value for anthocyanin content (12.5 mg/100g) was estimated from genotype PC-112, PC-172 had maximum juice content (597.9 mL/kg) and PC-161 had highest lycopene content *i.e.,* 1.67 mg/100g and all these outcomes were in line to various research works. According to Yadav *et al.* (2009) sugar content ranged from 7.0 to 7.8%. High anthocyanin content (1750 mg/kg) was found in black carrots with extraordinary quality parameters (Kirca *et al.,* 2006). Juice content is a vital trait related to the selection of genotypes suitable for processing (Kumar *et al*., 2010).

Temperate genotypes: Genotype PCP-17B had maximum root length (27.0 cm) while peak value for root weight was recorded in PCO-5 (123.7 g), Pusa Kulfi and PCO-20 have maximum root girth (3.5 cm) & flesh thickness (2.52 cm), respectively (Table 2). The marketable yield/plot was recorded highest for genotype PCP-2 (8.0 kg/plot). These results are in consonance with the findings of Yadav *et al.* (2009).

Genotype PCO-16 had maximum TSS content (9.7 °Brix), dry matter content was maximum in genotype PCO-16 (11.8%), and genotypes EC-3 and EC-5 have maximum total sugar content (5.2 %). PCO-5 had highest carotene content of 9.5 mg/100g while genotype Punjab Black Beauty had highest anthocyanin content 252.1 mg/100g. Similar trend of results were obtained by Ayyub *et al.* (2016) and Dongarwar *et al.* (2017). Orange and purple coloured carrots have higher concentrations of carotenoids in the cortex tissues (Perrin *et al.,* 2017). High Dry Matter content was reported in carrot genotypes by Poberezny *et al*. (2012).

Morphological characterization: Shape, color and flavor, etc. were surmised as selection criteria in the improvement of carrot (Grzebelus *et al*., 2014). The main colors include orange, purple, yellow, red, and white present in carrot cultivars (Kumar *et al.,* 2021). The purple carrots had more anthocyanin accumulation than that of yellow and orange carrots (Xu *et al*., 2016). Present set of genotypes for root color were categorized and shown in Fig. 1. Core colour of carrot is an important trait from processing point of view, self-colour core, light and very light yellow coloured core were present in many genotypes (Fig. 2).

Genotypic characterization *via* PCV, GCV, heritability and genetic gain: The extent of variability present in the carrot genotypes was measured in terms of range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (broad sense) and expected genetic advance as per cent of mean (Kaur *et al.,* 2005). Traits with less contribution to variability were excluded from final analysis of data. Magnitude of PCV was higher than corresponding GCV for all the characters for both tropical and temperate genotypes (Table 3). This was in line with the results obtained by Yadav *et al.* (2009) and Amin and Singla (2010). Priya and Santhi (2015) observed high GCV and PCV for carotene content in carrot.

The highest broad sense heritability was noticed for anthocyanin content (97%) followed by total sugar content (92.0 %). High heritability in carrot was reported by Jain *et al.* (2010) for fresh weight per plant, root weight and root length, by Yadav *et al*. (2009) for TSS and by Priya and Santhi (2015) for root carotene content and root weight. Kaur *et al*. (2009) also observed high heritability for TSS and carotene content in carrot.

Characters with high heritability can easily be fixed with simple selection resulting in quick progress (Meena *et al.*, 2016). Traits like anthocyanin content, lycopene content, total sugar content and carotene content possessed higher values of heritability, GCV and genetic gain. Selection for these characters would be effective in carrot improvement. High genetic gain was recorded by Jain *et al.* (2010) for fresh weight per plant, root weight and yield per hectare and by Amin and Singla (2010) for yield.

Results indicate that tropical genotypes have more vigor and superiority over temperate genotypes for high yield. While from biochemical point of view, temperate genotypes have superiority over tropical genotypes. To overcome the nutrition deficiency in human diet in India it's necessary to include the temperate types of carrot in food chain. For future hybridization programs, superior tropical and temperate genotypes can be selected to develop hybrids with high yield loaded with more concentration of biochemical compounds.

Combination of tropical and temperate genotypes in the carrot improvement program would be in terms of adaptability, enhanced root quality and yield. The results indicated that the genotypes vary in terms of quantitative and qualitative traits.

Table 1. Mean performance of Asian genotype for different characters

Genotypes	Plant height (cm)	Shoot weight (g)	Root length (cm)	Root weight (g)	Root Shoot ratio	Root girth (cm)	Core girth (cm)	Flesh thickness (cm)	Total yield (kg)	Marketable Yield (kg)	Maturity days	Number of leaves	TSS (°Brix)	Dry matter content (%)	Total sugar content (%)	Carotene content	Anthocyanin content	Juice content (mL/kg)	Lycopene content
PC-1	69.6	49.8	23.6	121.2	2.43	3.0	1.03	1.97	8.9	8.6	86.4	6.7	8.5	7.6	3.2	5.8	7.9	503.1	1.21
PC-2	69.5	43.9	26.1	118.7	2.70	2.9	0.87	2.03	8.8	8.4	86.9	7.3	8.5	7.6	3.9	6.8	3.8	470.8	0.99
PC-3	66.8	42.0	27.3	118.3	2.82	3.0	1.02	1.98	8.7	8.7	95.8	7.6	8.9	5.8	3.6	7.0	3.1	508.9	1.04
PC-4	61.3	44.2	23.8	116.0	2.62	3.1	0.91	2.19	8.5	8.2	95.3	8.2	8.4	7.7	4.2	7.3	8.3	507.4	0.70
PC-5	70.8	39.6	26.3	114.3	2.89	2.6	0.78	1.82	8.4	8.2	95.4	8.2	8.3	7.7	4.9	7.0	9.7	533.8	0.88
PC-5-1	69.4	52.5	26.4	107.4	2.05	2.7	0.96	1.74	7.8	7.6	99.3	7.8	8.6	6.8	3.5	6.6	5.4	534.5	1.03
PC-5-2	62.7	57.5	24.5	121.2	2.11	3.0	0.86	2.14	8.9	8.5	94.7	7.8	9.0	6.8	4.9	7.1	8.3	530.4	0.31
PC-6	69.8	47.8	26.1	117.1	2.45	2.5	0.77	1.73	8.6	8.2	90.5	7.7	8.8	6.6	4.8	6.5	8.7	426.1	1.11
PC-6-1	71.0	55.2	23.7	122.2	2.21	3.1	0.87	2.23	8.9	8.5	95.4	7.7	8.6	6.8	2.2	7.4	9.2	561.8	0.29
PC-7	72.2	44.7	22.2	120.6	2.70	3.0	1.15	1.85	9.0	8.5	92.7	7.8	8.9	9.2	4.1	6.4	9.6	496.7	0.97
PC-8	73.4	51.5	27.1	121.5	2.36	2.7	0.79	1.91	8.9	8.5	89.2	8.0	9.0	8.9	3.4	6.9	5.3	560.1	1.17
PC-9	68.3	47.9	26.6	121.6	2.54	2.9	0.86	2.04	8.8	8.4	94.4	8.9	8.6	7.0	4.0	7.7	3.8	528.4	0.97
PC-10	67.2	50.0	25.8	121.3	2.43	3.1	1.01	2.09	8.8	8.7	95.5	8.7	8.4	7.2	2.2	7.9	6.7	506.3	1.02
PC-11	75.4	49.7	21.5	109.3	2.20	3.3	0.85	2.45	8.2	7.7	92.6	8.2	8.4	9.2	4.6	7.1	8.0	414.2	1.38
PC-12	70.2	51.0	28.8	118.1	2.32	3.0	0.84	2.16	8.8	8.4	90.4	8.8	8.7	7.0	5.2	6.8	9.4	474.9	1.28
PC-13	57.1	52.8	26.0	126.2	2.33	2.8	1.02	1.78	9.0	8.7	91.0	7.3	8.7	7.0	3.3	7.6	6.8	454.9	0.33
PC-14	62.9	44.5	23.6	118.6	2.67	3.0	1.24	1.76	8.8	8.4	94.0	8.5	8.5	6.8	3.9	5.7	12.2	499.6	0.24
PC-15	66.3	48.5	26.7	124.4	2.56	3.0	0.95	2.05	9.2	8.8	91.3	9.3	9.4	7.2	4.3	7.7	3.4	544.9	1.07
PC-16	67.7	47.2	29.0	116.2	2.46	2.7	0.80	1.90	8.4	8.2	93.6	8.8	8.5	7.0	2.8	7.5	8.3	554.8	1.60
PC-17	68.6	46.5	30.8	120.2	2.58	3.0	0.83	2.17	8.8	8.5	96.4	7.8	9.0	7.0	3.1	6.4	3.9	591.1	1.20
PC-34	66.8	42.9	26.9	116.7	2.72	3.1	0.95	2.15	8.5	8.4	91.3	6.7	9.7	10.9	5.1	7.8	8.7	495.7	1.06
PC-43	70.9	43.2	23.6	124.4	2.88	2.8	0.83	1.97	9.2	8.7	92.5	7.6	8.8	7.2	4.7	6.4	3.8	572.9	0.95
PC-69	66.5	46.0	24.9	122.4	2.66	3.0	0.94	2.06	8.9	8.8	89.6	7.8	8.7	6.6	4.7	7.2	3.3	468.8	0.95
PC-79 A	68.9	49.3	29.0	123.6	2.51	2.9	0.75	2.15	9.1	8.6	91.6	8.3	9.4	7.3	5.2	6.3	8.1	492.8	1.65
PC-79 B	71.8	48.9	23.7	116.0	2.37	3.0	0.99	2.01	8.5	8.3	96.7	8.6	9.0	6.8	3.4	6.6	8.3	481.0	1.25
PC-80	71.7	50.7	28.0	122.0	2.41	3.0	0.98	2.02	9.1	8.6	90.5	8.1	8.8	6.7	3.1	6.1	7.8	503.0	0.26
PC-100	60.3	44.9	22.9	121.5	2.71	3.1	0.93	2.17	8.9	8.5	89.2	7.3	8.5	6.2	4.9	7.6	3.2	529.0	1.09
PC-103	74.6	45.1	25.4	124.1	2.75	3.2	0.84	2.36	9.2	8.8	90.5	8.9	9.0	6.9	4.5	6.9	8.5	444.1	1.12
PC-105	67.9	44.7	24.2	117.3	2.62	3.3	1.35	1.95	8.7	8.4	99.9	8.4	8.9	5.9	4.8	7.4	7.8	543.8	0.79
PC-112	71.7	52.5	28.3	119.3	2.27	3.3	1.03	2.27	8.7	8.3	97.2	7.8	8.6	7.3	4.9	7.2	12.5	571.0	0.30
PC-141	65.7	44.8	24.0	122.9	2.74	2.9	1.10	1.80	9.0	8.7	88.4	8.1	8.9	7.0	3.1	5.2	11.0	531.9	0.87
PC-142	71.5	54.5	22.7	119.8	2.20	2.8	1.14	1.66	8.7	8.5	94.8	8.7	8.8	7.3	4.5	6.5	8.7	423.5	1.35
PC-143	75.8	50.6	22.2	114.2	2.26	3.0	1.00	2.00	8.5	8.4	87.6	8.2	8.1	7.0	4.8	7.0	4.8	446.2	0.92
PC-144	60.2	45.0	24.7	122.5	2.72	3.2	1.03	2.17	9.0	8.6	94.5	8.2	8.8	6.7	4.4	6.6	6.5	472.5	0.34
PC-160	68.9	48.3	26.3	122.8	2.54	3.1	0.78	2.32	9.1	8.6	91.4	8.2	8.6	6.8	4.9	6.6	7.4	514.7	1.13
PC-161	73.5	48.5	30.0	127.2	2.62	3.0	0.69	2.31	9.3	9.2	90.5	8.2	9.5	9.7	5.3	8.7	8.4	583.5	1.67
PC-171	68.9	54.5	29.3	123.6	2.27	2.7	0.67	2.03	8.9	8.9	92.9	8.2	8.3	6.8	5.0	6.6	11.3	550.0	1.06
PC-172	67.0	52.1	26.0	120.2	2.31	2.8	0.94	1.86	8.8	8.4	90.0	9.4	8.8	6.5	5.3	7.9	12.3	597.9	0.98
PC-173	70.2	49.0	26.2	126.0	2.57	3.4	1.05	2.35	9.1	9.0	92.4	8.6	9.4	8.7	5.3	7.8	5.5	582.3	1.03
PC-174	67.6	47.1	23.5	119.8	2.54	3.0	0.84	2.16	8.8	8.3	96.5	7.3	8.6	8.0	2.9	6.0	11.9	484.0	1.39
PC-175	69.6	49.8	26.1	118.7	2.38	2.9	0.87	2.03	8.8	8.4	86.9	7.3	8.7	7.0	4.2	6.8	6.7	454.9	1.00
PC-176	71.5	54.5	24.0	122.9	2.26	2.9	1.10	1.80	9.0	8.7	88.4	8.1	8.5	6.8	3.1	5.2	8.0	499.6	1.60
PC-177	66.3	48.5	24.7	122.5	2.53	3.2	1.03	2.17	9.0	8.6	94.5	8.2	8.4	7.2	5.3	6.8	9.4	506.3	1.20
Karnana-1	63.9	45.0	26.6	123.1	2.74	3.1	0.93	2.17	9.0	8.5	90.3	8.5	8.6	7.0	4.7	7.5	3.1	520.7	0.92
Pusa Vrishti	55.0	47.5	24.3	124.0	2.61	3.4	0.84	2.56	8.9	8.7	94.0	6.5	8.6	6.2	4.7	6.8	3.8	556.9	1.06
Pusa Rudira	73.0	46.4	25.8	112.6	2.43	2.6	0.85	1.75	8.3	8.0	89.3	8.4	8.7	6.4	5.0	7.0	9.6	552.0	1.13
Pusa Vasuda	74.5	47.8	26.1	118.8	2.49	2.8	0.84	1.96	8.7	8.4	95.3	8.5	8.6	7.3	5.3	7.6	5.3	437.2	1.11
Hisar Gairic	69.6	48.1	24.9	111.8	2.32	2.8	0.81	1.99	8.2	8.1	94.7	7.4	8.4	6.2	4.6	7.2	3.2	464.9	1.04
PCD	65.6	50.4	27.4	114.7	2.28	2.9	0.79	2.11	8.2	8.1	88.9	7.9	9.2	10.0	5.0	7.4	10.4	515.3	1.30
Mean	68.4	48.3	25.7	119.7	2.49	3.0	0.92	2.02	8.8	8.5	92.47	8.1	8.7	7.28	4.2	6.9	7.35	510.2	0.99
Range	55.0-75.8	39.6-57.5	21.5-30.8	107.4-127.2	2.05-2.89	2.5-3.4	0.67-1.35	1.65-2.56	7.8-9.3	7.6-9.2	86.4-99.9	6.5-9.4	8.1-9.7	5.8-10.9	2.1-5.3	5.2-8.7	3.1-12.5	414.2-597.9	0.24-1.67
CD at 5%	5.9	5.19	3.82	6.90	0.22	0.39	0.04	0.12	0.45	0.47	4.53	0.52	0.37	0.52	0.43	0.45	0.42	21.8	0.08

PCD=Punjab Carrot Red

Table 2. Mean performance of European genotype for different characters

Genotypes	Plant height (cm)	Shoot weight (g)	Root length (cm)	Root weight (g)	Root Shoot ratio	Root girth (cm)	Core girth (cm)	Flesh thickness	Total yield (kg)	Marketable Yield (kg)	Maturity days	Number of leaves	TSS (°Brix)	Dry matter content (%)	Total sugar content (%)	Carotene content	Anthocyanin content	Juice content (mL/kg)	Lycopene content
PCO-1	56.2	40.5	15.6	110.2	2.72	2.9	0.62	2.28	6.4	6.2	102.5	7.1	8.8	9.7	4.7	7.6	7.1	441.3	0.25
PCO-3	64.9	40.6	21.3	111.8	2.75	2.9	0.78	2.12	6.3	6.2	97.6	6.0	9.3	10.9	4.8	7.3	9.7	546.8	0.34
PCO-4	55.0	43.2	20.8	111.6	2.58	3.2	0.69	2.51	6.1	6.1	106.1	7.0	8.6	10.0	4.6	7.9	4.7	548.5	0.97
PCO-5	58.6	43.4	24.0	123.7	2.85	3.2	0.92	2.28	6.9	6.7	97.9	6.9	9.5	10.6	5.0	9.5	4.1	568.9	0.96
PCO-7	60.6	32.3	23.4	122.9	3.80	2.9	0.79	2.11	6.6	6.4	97.1	6.7	9.0	10.3	4.5	8.0	9.7	488.9	1.19
PCO-7-1	56.9	37.7	18.0	112.2	2.97	2.9	0.96	1.94	6.2	6.5	98.4	7.6	8.8	10.7	4.7	7.5	7.8	466.0	1.00
PCO-8	61.5	37.2	15.7	115.0	3.09	3.1	0.85	2.25	6.2	5.9	109.2	6.9	9.2	9.8	4.4	8.5	9.2	526.3	0.24
PCO-13	56.2	39.0	20.7	113.5	2.91	3.1	0.79	2.31	6.3	6.0	99.1	7.2	9.3	10.4	4.7	8.0	10.5	514.9	0.21
PCO-14	56.8	36.1	13.8	110.6	3.06	3.2	0.73	2.47	6.4	5.9	98.1	7.0	8.7	9.9	4.9	7.4	3.9	539.2	1.05
PCO-15	57.1	36.5	16.7	112.7	3.08	2.8	0.84	1.96	6.1	5.8	100.0	6.2	9.2	10.6	4.7	8.6	5.8	568.9	0.91
PCO-16	65.5	39.7	17.2	103.5	2.60	3.0	0.75	2.25	5.0	5.0	100.5	7.8	9.7	11.8	4.9	9.1	8.6	510.9	1.07
PCO-17	60.6	33.7	22.0	119.5	3.55	3.2	0.87	2.33	6.5	6.2	99.4	7.4	9.6	10.7	5.1	7.8	10.0	567.9	1.22
PCO-18	57.0	43.3	17.6	101.4	2.34	2.8	0.82	1.98	5.8	5.7	100.8	6.7	9.6	11.4	4.9	9.0	8.5	486.9	0.94
PCO-19	61.3	40.6	19.3	118.2	2.91	2.8	0.76	2.04	6.9	6.7	97.5	7.1	9.6	10.8	4.6	7.9	4.2	425.5	0.97
PCO-20	52.3	30.1	21.0	121.7	4.04	3.3	0.78	2.52	6.8	6.6	97.7	7.0	9.5	10.3	5.0	7.4	10.2	555.9	0.24
PCO-24	54.5	43.8	14.8	109.8	2.51	3.0	0.99	2.01	6.0	5.8	96.1	6.6	8.7	10.7	5.0	7.7	4.6	541.6	1.11
PCO-30	59.6	34.6	24.9	120.6	3.49	3.2	0.96	2.24	6.9	6.7	105.4	7.1	9.2	10.7	5.1	9.0	9.1	571.9	0.33
EC-1	62.6	46.9	18.0	114.7	2.45	2.8	0.9	1.90	6.0	5.7	97.9	7.7	8.6	10.6	4.7	7.1	6.2	481.1	0.93
EC-2	57.3	47.0	20.1	109.7	2.33	2.8	0.83	1.97	6.1	5.9	100.5	6.6	9.0	9.4	4.9	7.5	9.5	501.1	1.09
EC-3	57.5	42.5	23.8	119.0	2.80	3.2	0.87	2.33	5.5	5.3	104.2	6.3	8.6	10.7	5.2	7.4	8.6	577.6	1.66
EC-4	58.5	43.3	18.4	111.9	2.58	3.1	0.66	2.44	5.9	5.8	99.4	6.5	9.1	10.6	4.5	7.1	9.4	543.6	0.24
EC-5	50.8	33.1	18.2	118.1	3.57	2.9	0.88	2.02	5.6	5.5	101.8	5.5	9.3	10.6	5.2	7.8	11.1	435.8	1.36
EC-6	55.3	37.7	16.8	115.2	3.06	2.9	0.85	2.05	6.3	6.0	99.3	7.0	9.3	10.5	4.6	9.3	11.0	459.8	0.28
EC-16-6	47.0	37.4	18.7	118.5	3.15	3.0	0.81	2.19	6.6	6.3	98.7	6.7	9.0	10.2	4.5	8.6	8.0	473.2	0.84
Pusa Meghali	58.3	44.7	20.8	113.7	2.54	3.1	0.68	2.42	6.1	5.9	99.7	7.0	8.6	10.7	5.0	7.0	9.9	536.2	1.39
Arka Suraj	59.7	47.5	20.0	112.9	2.38	2.9	1.05	1.85	6.1	6.0	100.5	6.5	9.3	10.2	4.5	7.5	11.2	528.8	0.87
PCY-1	65.7	44.0	25.3	103.9	2.36	2.8	0.89	1.91	5.1	4.7	102.1	7.7	9.6	8.6	3.2	6.9	8.9	470.7	1.39
Pusa Kulfi	64.1	41.3	23.4	119.5	2.89	3.5	1.11	2.39	5.3	5.2	94.8	7.6	9.5	7.7	3.2	6.7	10.4	448.8	1.29
PCP-1	57.9	37.4	25.7	121.5	3.20	3.1	0.99	2.11	7.9	7.7	98.5	6.8	9.3	9.0	3.3	4.6	107.0	473.1	0.32
PCP-2	67.5	46.6	26.3	123.1	2.64	3.2	1.06	2.14	8.2	8.0	101.0	6.3	8.8	8.5	3.1	5.0	85.3	513.2	0.2
PCP-17A	57.4	40.0	22.8	110.9	2.77	3.0	1.07	1.93	7.6	7.4	89.4	7.4	8.9	8.6	3.0	3.5	92.0	474.4	0.66
PCP-17B	61.8	39.7	27.0	120.0	3.02	3.0	0.9	2.10	7.8	7.6	92.7	6.9	9.0	8.5	2.8	3.4	83.9	538.6	0.24
PCB-2	70.0	38.8	25.2	118.7	3.05	3.1	0.96	2.14	7.7	7.6	97.4	6.5	9.1	7.9	3.2	3.3	180.4	509.0	1.13
Pusa Asita	66.1	43.1	24.3	115.1	2.66	2.9	1.18	1.72	4.9	4.9	91.7	6.9	9.1	9.3	3.0	2.8	135.5	379.5	1.57
PBB	74.5	42.7	25.4	113.6	2.65	2.7	0.85	1.85	7.2	7.1	88.8	7.4	8.1	10.4	3.1	2.3	252.1	575.0	0.32
PCW	71.5	42.8	22.0	116.0	2.70	3.1	1.11	1.99	6.9	6.7	90.4	7.5	8.1	9.0	3.0	5.4	4.7	467.3	0.87
Over Mean	59.9	40.2	20.8	114.9	2.89	3.0	0.88	2.14	6.4	6.2	98.7	6.9	9.1	10.0	4.3	6.9	32.6	507.1	0.80
Range	47.0-74.5	30.1-47.5	13.8-27.0	101.4-123.7	2.33-4.04	2.7-3.5	0.62-1.18	1.72-2.52	4.9-8.2	4.7-8.0	88.8-109.2	5.5-7.7	8.1-9.7	7.7-11.8	2.8-5.2	2.3-9.5	3.9-252.1	379.5-577.6	0.20-1.66
CD at 5%	6.6	6.1	4.1	8.3	0.32	0.38	0.14	0.23	0.68	0.63	6.7	0.91	0.59	0.97	0.49	1.4	4.2	58.3	0.42

Table 3. Estimates of parameters of variability for different traits in tropical and temperate carrot

Characters	Tropical carrot						Temperate carrot					
	GCV (%)	PCV (%)	h² (%)	GA	Genetic Gain	General Mean	GCV (%)	PCV (%)	h² (%)	GA	Genetic Gain	General Mean
Root weight	2.8	5.6	25	3.5	2.9	119.6	4.8	6.6	53	8.36	7.3	115.1
Days to 1st root harvest	2.9	4.8	37	3.4	3.7	92.7	4.1	5.4	56	6.21	6.3	98.7
Root girth (cm)	4.9	11.2	19	0.13	4.5	2.9	3.6	9.9	13	0.08	2.6	2.9
Dry matter content (%)	13.3	14.1	89	2.01	25.8	7.7	5.2	6.9	56	0.85	8.0	10.6
Total sugar content (%)	22.6	23.6	92	1.85	44.8	4.1	17.7	18.7	89	1.47	34.5	4.3
Carotene content (mg/100g)	7.9	9.0	77	1.14	14.4	7.9	27.2	27.5	97	3.82	55.2	6.9
Anthocyanin content (mg/100g)	38.4	39.0	97	5.60	77.7	7.2	179.9	179.9	99	117.24	370.6	31.6
Lycopene content (mg/100g)	34.1	39.4	75	0.60	60.9	0.99	55.8	56.8	96	0.91	112.9	0.8

* GCV - genotypic coefficient of variation, PCV - phenotypic coefficient of variation, h2 - heritability in broad sense, GA - genetic advance

Fig.1. Variation in root colour of carrot genotypes

Fig. 2. Variation in core and cortex of carrot genotypes

Genotypes PC-161, PC-15, PC-173 (Red), PCO-30, PCO-5, PCO-7 (Orange) PCP-2, PCP-1 and PCP-17B (Purple) were found superior for total and marketable yield with other horticultural and biochemical traits hence these genotypes can be used in the future breeding programs or can be released directly as a variety. Traits like total sugar content (%), carotene content (mg/100g), anthocyanin content (mg/100g) and lycopene content (mg/100g) had higher values of GCV, heritability and genetic gain and were found most important traits for applying selection for crop improvement.

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Received: April, 2021; Revised: June, 2021; Accepted: June, 2021