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Breeding tropical carrots (*Daucus carota*) for enhanced nutrition and high temperature stress

SWATI SAHA[1], PRITAM KALIA[2], AMISH KUMAR SUREJA[3] and S SARKAR[4]

ICAR–Indian Agricultural Research Institute, Pusa, New Delhi 110 012

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ABSTRACT

Carrot (*Daucus carota* L.) is a globally important vegetable crop providing a source of important nutritional compounds through carotenoid content whilst adding flavour and texture to many diets. Temperature influences growth, yield and quality of carrots in many different ways. The influence of varying temperatures on yield and quality parameters of carrots has been a topic for research during the last three decades. An attempt was done to analyze inbreds for quantitative and qualitative traits for the selection of inbreds for high temperature stress. The inbreds showed variation in plant weight, foliage weight, root weight, root length and root girth with average of 233.71g, 74.16g, 164.13g, 21.62 cm, whereas root girth ranged from 4.77-3.70 cm respectively. Anthocyanin content estimated to be highest in dark purple black inbred line IPC-126 (333.81 mg/100g) while the total carotenoid content was highest in root tissue of IPC-124 (14.46 mg/100g). The lycopene content ranged from 0.50 mg/100g (IPC-126) to 11.85 mg/100g (IPC-124). TSS ranged from 6.7 to 10.48 °Brix. Some inbreds performed well under extreme high temperature without affecting any quality attributes. Such inbreds could be selected for further breeding program. The results of our study will help in development of high quality superior hybrids using the promising inbreds in tropical carrot.

Key words: *Daucus carota*, Inbreds, Nutritional profiling, Quantitative traits

Carrot (*Daucus carota* L.) is a cool season vegetable crop, performing well under cooler weather (10 to 25°C). Temperature has an effect on plant growth mainly on the rate of chemical reactions, and consequently the usage of photosynthetic products and hence affecting the production of carrots. Moderate day and relatively low night temperatures during storage root formation improve carbohydrate accumulation in carrots. At temperatures above 25°C results in unmarketable roots with low yields. Temperatures below 10ºC and above 30ºC results in lighter colour (Rosenfeld 1998a).

More productive cultivars and hybrids of crops such as carrot with a higher nutritional content need to be developed to ensure global access to a secure, balanced diet (Dias 2010). With the increasing rise in temperature every year, it is essential to breed cultivars or hybrids under such climatic change. Therefore our attempt was to breed tropical carrot inbreds under high temperature stress with enhanced nutrition.

[1]Scientist (e mail: swatisaha1980@gmail.com),[2]Head (e mail: pritam.kalia@gmail.com), [3]Senior Scientist (e mail: aksureja@gmail.com), Division of Vegetable Science, [4]Scientist Senior Scale (e mail: sarkar82@gmail.com), Indian Agricultural Statistics Research Institute, New Delhi.

MATERIALS AND METHODS

Thirty eight inbreds of tropical carrot were evaluated for different quantitative and nutritional traits for four consecutive years (2009-2012). Based on the average data of four seasons, the qualitative and the quantitative parameters were worked out. The inbreds were sown in the hot and humid month of July when the temperature varies from 30-32°C. The experiment was conducted in the Vegetable Research Farm of Indian Agricultural Research Institute, New Delhi with Randomised Block Design as the experimental design and with three replicates. The climatic conditions are given in the Table 1 to have a glimpse of weather during its growth period. The objective of the study was to have some good heat tolerant inbreds under extreme heat stress condition.

Well developed and matured carrot roots of all inbreds were harvested on same day. The roots were properly cleaned with tap water to remove the dust particles. For estimating anthocyanins, roots were crushed in ethanolic hydrochloride solution and kept overnight at 4^0C. The extract was filtered and again kept for 2 hr in dark. Anthocyanin was recorded at 535 nm wavelength and expressed in mg/100 g fresh weight. Similarly total carotenoids and lycopene were extracted in acetone. The extract was filtered and then transfered in the separating funnel containing petroleum ether, sodium sulphate and

Table 1 Meterological data of IARI from 2009-2012

Year	T Max (°C)	T Min (°C)	TAvg (°C)	RH1 (%)	RH2 (%)	RHAvg (%)	RF (mm)	SS (hr)	Wind (km/hr)
2009									
JUN	41.3	27.4	34.3	54.4	33.9	44.1	0.2	8.7	6.3
JUL	35.8	26.6	31.2	76.9	59.5	68.2	4.0	6.1	2.7
AUG	34.7	26.1	30.4	77.2	61.3	69.3	6.1	5.8	2.3
SEP	33.4	23.2	28.3	88.1	57.4	72.8	6.7	7.1	2.8
OCT	32.7	16.4	24.6	84.7	36.8	60.8	0.0	7.6	3.1
2010									
JUN	40.6	27.3	33.9	50.1	28.1	39.1	0.2	5.9	8.5
JUL	34.7	26.6	30.7	83.5	66.3	74.9	7.7	4.1	6.2
AUG	32.3	25.6	29.0	92.1	75.5	83.8	11.1	3.1	2.5
SEP	30.9	23.6	27.2	95.1	76.5	85.8	10.5	3.8	2.1
OCT	32.1	18.7	25.4	88.0	47.3	67.6	0.7	6.2	1.6
2011									
JUN	37.1	25.8	31.5	74.7	52.7	63.7	3.5	5.6	6.3
JUL	34.3	26.0	30.2	86.8	68.5	77.6	1.4	2.6	4.7
AUG	33.2	25.7	29.4	87.3	75.6	81.5	7.3	4.2	1.2
SEP	33.3	24.4	28.9	90.0	70.6	80.3	5.5	6.5	4.7
OCT	32.8	17.5	25.2	82.6	36.5	59.6	0.0	7.0	4.0
2012									
JUN	42.6	29.0	35.8	45.5	26.4	36.0	0.4	7.1	10.5
JUL	36.5	27.6	32.1	78.8	60.3	69.5	4.5	4.5	6.6
AUG	32.5	25.7	29.1	86.9	76.2	81.5	8.8	2.3	4.7
SEP	33.4	24.0	28.7	86.5	59.3	72.9	1.9	6.0	4.7
OCT	32.6	16.1	24.3	87.6	41.9	64.8	0.4	7.3	3.0

TMax = Temperature maximum, Tmin = Temperature minimum, TAvg = Temperature average, RH1 = Relative humidity morning, RH2 = Relative humidity evening, RHAvg = Relative humidity average, RF = Rainfall, SS = Sunshine

distilled water. The mixture was mixed gently resulting in the separation of two phases. The upper extract was collected and measured in 452 nm for total carotenoids and 503 nm for lycopene. Both expressed in mg/100g fresh weight. The total soluble solids were measured by refractrometer.

The carrot roots were crushed and juice was extracted. A drop of crushed carrot juice was placed in the refractrometer and reading was expressed in °Brix. Field fresh carrot sample was washed and wiped with tissue paper so as to absorb the water and immediately the fresh weight was recorded. The sample was cut into small pieces, kept in dried petri plates and dried to a constant weight, at a temperature not exceeding 70ºC in hot oven. The dried sample was allowed to cool and dry weight was recorded. The moisture content was expressed in percentage. The four year data with three replications was pooled and was statistically analysed using Statistical Analysis Software, Version 9.3 (SAS 2010). The sample similarities were calculated on the basis of pair-wise Euclidean distance and the unweighted pair-group method with arithmetic averaging (UPGMA) algorithm was used for establishing cluster to search natural groupings among the genotypes for morphological and biochemical parameters. Mean values were calculated along with the critical difference and coefficient of variation for different parameters.

RESULTS AND DISCUSSION

The inbreds assessed showed variation in plant weight, which ranged from 178.23 g to 289.19 g. From the pooled data (Table 1), maximum plant weight was recorded in IPC-8 (289.19g), followed by IPC-4 (273.18g). The carrot root which is the economic part also showed variation in weight ranging from 114.24g to 214.02 g. Maximum root weight was observed in IPC-8 (214.02 g), followed by IPC-4 (203.48 g). Similarly there was a significant variation in the root length and root girth. Root length varied from 18.92 cm (IPC-31) to 24.32 cm (IPC-126) whereas root girth ranged from 3.47 cm (IPC-122) to 4.47 cm (IPC-53). IPC -126 for root length (24.32 cm) and IPC-53 for root girth (4.47 cm) were found promising. Carrot inbreds were also assessed for external and internal root colour after harvest which is an important criteria from consumer point, as better colour will have more attraction for consumers. Most of the inbreds were red, but some were orange, purple etc. The lycopene rich red carrots are in high demand in India due to their multiple uses like in juice, salad, cooking, pickle, pudding making and sweets.

Growing conditions such as temperature, soil moisture, rainfall, light intensity and day length have a significant effect on the yield and quality of carrot roots.

The influence of varying temperatures on yield and quality parameters of carrots has been a topic for research during the last three decades (Rosenfeld and Samuelsen 2000). Therefore the breeding efforts should be concentrated towards selection of high temperature tolerant inbred along with enhanced nutritional value and yield. The four years of intense selection towards quantitative and qualitative traits has resulted in the selection of promising inbreds for high temperature stress. Breeding carrots for high temperature stress with improved quality traits will not only benefit the producers but also the consumers. Variation in quantitative traits over the years may purely be due to genetic as well as environmental factors.

Simon and Wolf (1987) also reported varied performance of cultivars with regard to genotype, location and season. The root yield ranged from 114.24 to 214.02 g. Some of the high yielding inbreds with good root weight were IPC-8, IPC-4 and IPC-116. Along with the root weight, root girth and root length are also important criteria for selection. Variation was observed in root length and root girth among different inbreds, but IPC-8 and IPC-4 were found best for all the quantitative traits studied.

Carrots are globally important providing important nutritional compounds (including pro-vitamin A) through their carotenoid content whilst adding flavour and texture to many diets across the world (Heinonen 1990). The different quality attributes showed significant differences. Maximum anthocyanin was noted in IPC-126 (333.81 mg/ 100g) which is a dark purple black carrot inbred. The total

Table 1 Quantitative and morphological traits in tropical carrot inbreds

Inbred	Plant height (cm)	Plant weight (g)	Foliage weight (g)	Root weight (g)	Root length (cm)	Root girth (cm)	Colour
IPC - 109	76.33	224.32	73.75	150.57	22.52	3.81	Red
IPC - 031	86.33	242.60	74.20	168.40	18.92	4.02	Red
IPC - 085	71.46	229.66	76.61	153.05	22.25	4.06	Red
IPC - 011	87.33	235.27	73.34	161.93	21.41	4.10	Red
IPC - 061	78.33	211.44	74.67	136.77	22.18	3.88	Red
IPC - 118	69.10	200.39	66.19	134.02	21.98	3.76	Red
IPC - 106	83.76	203.46	73.25	130.21	20.93	3.95	Red
IPC - 124	79.66	178.23	60.02	118.21	21.33	3.51	Red
IPC - 039	85.66	212.82	72.67	140.15	19.32	3.93	Red
IPC - 011	85.86	218.20	70.13	148.07	20.81	3.72	Orange
IPC - 007	74.33	187.51	73.27	114.24	21.03	3.86	Red
IPC - 004	83.20	273.18	69.70	203.48	22.04	4.07	Red
IPC - 008	89.23	289.19	75.17	214.02	21.92	4.33	Red
IPC - 098	90.20	231.64	66.35	165.29	23.14	4.12	Red
IPC - 123	87.63	245.48	94.67	150.81	21.97	3.87	Red
IPC - 034	87.90	220.06	66.16	153.09	22.85	3.90	Red
IPC - 029	83.23	248.96	85.05	163.91	20.86	3.81	Orange
IPC - 053	86.66	209.52	62.47	147.05	23.88	4.47	Red
IPC - 104	79.10	188.57	53.66	134.91	20.95	3.81	Orange
IPC - Ht-2	84.46	234.96	77.09	157.87	20.18	3.85	Red
IPC - 116	91.23	266.60	83.30	183.03	22.42	3.82	Red
IPC -076	87.56	226.74	72.14	154.06	21.08	3.84	Red
IPC -013	91.33	242.29	77.28	165.01	22.02	4.06	Red
IPC - 055	84.33	228.63	73.13	155.05	22.67	4.37	Red
IPC - 122	81.23	186.96	66.60	120.36	21.16	3.47	Red
IPC - 010	55.33	215.84	61.59	154.25	20.69	4.03	Red
IPC - 001	86.76	248.03	69.83	178.02	20.79	4.30	Red
IPC - 035	57.43	226.82	66.49	160.33	20.74	4.12	Red
IPC - 075	83.00	218.58	70.34	148.24	22.55	4.09	Red
IPC - 126	88.13	227.29	78.30	148.99	24.32	3.99	Dark purple
IPC - 096	72.10	210.89	73.67	137.22	20.86	4.09	Red
IPC - 020	83.76	225.98	77.66	148.32	20.98	3.86	Purple red
IPC - 105	90.10	233.49	80.51	152.98	21.79	3.90	Red
IPC - 005	73.33	204.07	65.07	139.00	20.38	3.70	Red
IPC - 013	92.56	205.41	65.97	139.44	20.83	4.17	Orange
IPC - 030	81.76	225.45	68.72	156.73	19.80	4.15	Red
IPC - 025	84.66	238.28	67.03	171.25	20.17	4.05	Red
IPC - 091	71.23	187.82	58.08	129.74	22.10	4.02	Light red
CD	21.54	34.43	3.30	31.32	4.57	1.65	
CV (%)	16.34	19.17	14.23	15.61	13.56	10.60	

carotenoid content in root tissue varied considerably among the inbreds. The breeding material contained maximum total carotenoid in IPC-124 (14.46 mg/100g) followed by IPC-11 red (9.99 mg/100g). Root colour is also an indication of carotenoid content. Orange roots contained on an average 6.78 mg/100g of carotenoid with maximum in IPC-13 orange (9.77 mg/100g), whereas black carrot had minimum total carotenoids (1.18 mg/100g). The lycopene content ranged from 2.07 mg/100g (IPC-11 orange) to 11.85 mg/100g (IPC-124, Table 2). Optimum temperature required for proper growth and good colour development varies from 15.5 – 21.1°C. Carotene content decreases above 21.1°C and below 15.5°C (Bose and Som 1986). IPC-124, IPC-13, IPC-11 red, IPC-11 orange and IPC-126 were found promising inbreds in respect of qualitative traits. The inbreds performed well under extreme high temperature without affecting any quality attributes. Such inbreds could be selected for further breeding program.

Black carrot (IPC-126) had very less (0.50 mg/100g) lycopene content. The TSS in the 38 inbreds ranged from 6.7°Brix to 10.48 °Brix. IPC-126 showed maximum TSS (10.48 °Brix), followed by IPC-118 (10.09°Brix). The moisture content were highest in IPC-34 (94.75%), followed by IPC-7 (93.91%). Dris & Jain (2004) have indicated that the total

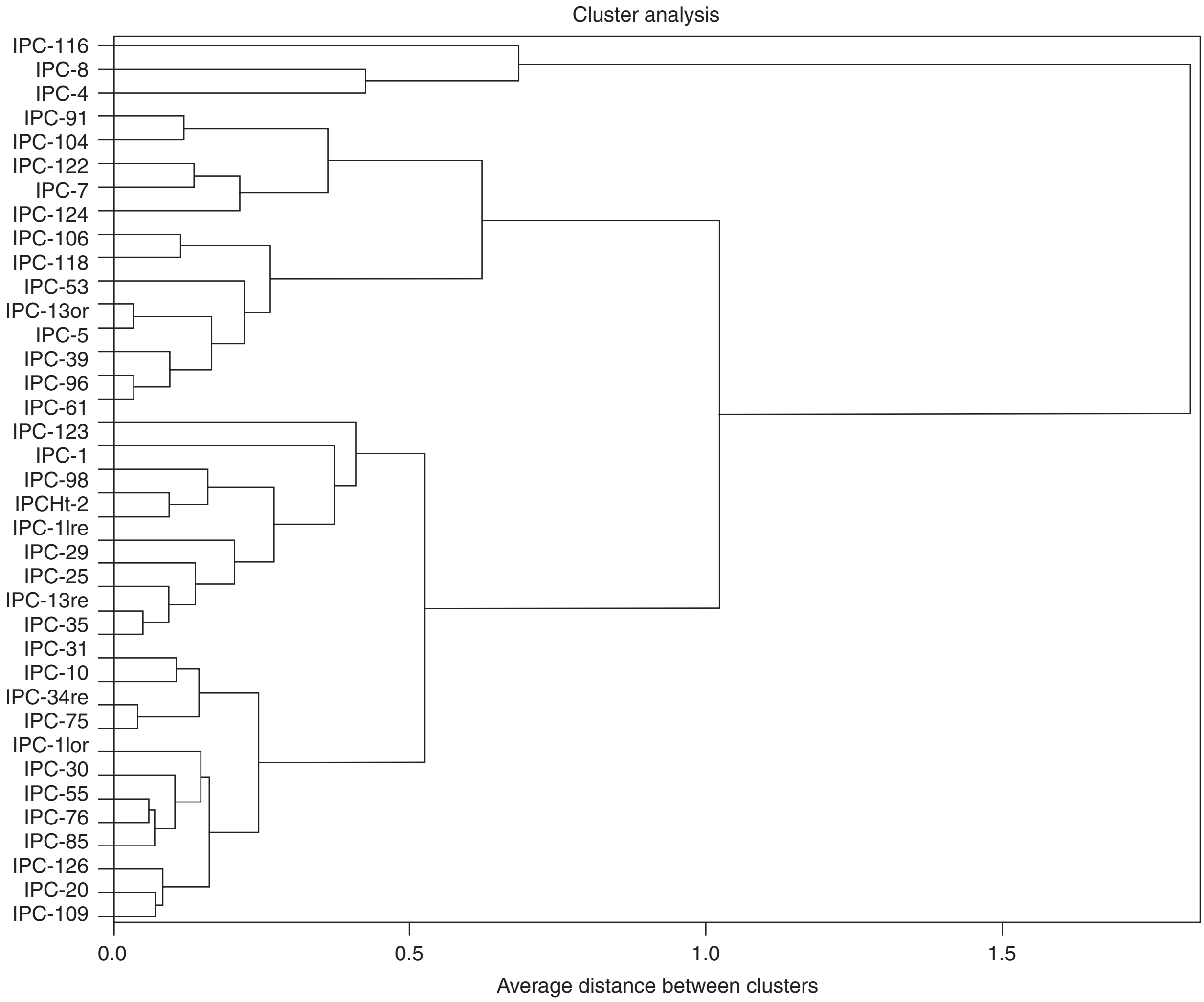

Fig 1 Cluster analysis of quantitative traits in tropical carrot inbreds

Table 2 Quality traits in tropical carrot inbreds

Inbred	Anthocyanin (mg/100g fw)	Total carotenoids (mg/100g fw)	Lycopene (mg/100g fw)	TSS (°Brix)	Moisture per cent
1	2	3	4	5	6
IPC-109	0.19	7.91	6.33	8.41	92.73
IPC-031	0.14	9.27	7.85	7.74	90.82
IPC-085	0.46	7.63	6.02	8.49	93.17
IPC-011	0.21	9.99	8.20	8.22	92.54
IPC-061	0.52	8.10	7.80	8.79	89.42
IPC-118	0.26	8.86	7.57	10.09	92.85
IPC-106	0.39	5.82	4.65	9.07	91.23
IPC-124	0.14	14.46	11.85	9.03	92.48
IPC-039	0.31	5.40	5.48	7.94	91.32
IPC-011	0.25	4.86	2.07	8.35	88.50
IPC-007	0.21	7.77	6.33	7.57	93.91
IPC-004	0.25	7.22	5.65	9.08	90.91
IPC-008	0.31	8.62	7.73	7.93	89.28
IPC-098	0.22	6.16	5.45	8.30	92.99
IPC-123	0.18	6.71	6.16	8.79	92.33
IPC-034	0.23	8.74	7.11	7.93	94.75
IPC-029	0.51	5.76	2.12	7.74	92.98
IPC-053	0.20	5.66	4.91	9.76	92.15

Contd.

Table 2 (*concluded*)

1	2	3	4	5	6
IPC-104	0.31	6.73	2.56	8.90	91.10
IPC Ht-2	0.04	6.91	5.24	9.14	92.47
IPC-116	0.12	5.42	3.41	7.83	92.77
IPC-076	0.17	8.28	6.73	8.62	92.63
IPC-013	0.61	6.52	5.18	7.23	93.28
IPC-055	0.14	5.50	5.17	6.76	92.56
IPC-122	0.19	9.00	8.19	7.23	93.13
IPC-010	0.19	6.61	5.09	7.82	92.42
IPC-001	0.17	9.51	7.31	8.21	92.72
IPC-035	0.13	5.85	4.92	7.39	93.37
IPC-075	0.23	5.18	4.24	7.15	92.24
IPC-126	333.81	1.18	0.50	10.48	89.21
IPC-096	0.25	5.96	5.31	6.87	92.63
IPC-020	4.74	5.87	4.66	8.42	90.55
IPC-105	0.35	8.36	6.96	9.67	90.91
IPC-005	0.36	7.27	7.29	6.70	92.83
IPC-013	0.36	9.77	8.11	8.27	90.58
IPC-030	0.31	6.84	8.93	8.55	87.98
IPC-025	0.18	7.96	9.75	8.71	93.35
IPC-091	0.10	6.62	10.58	8.80	93.39
CD	0.51	2.17	1.48	0.52	1.70
CV (%)	4.82	12.47	15.88	5.57	1.62

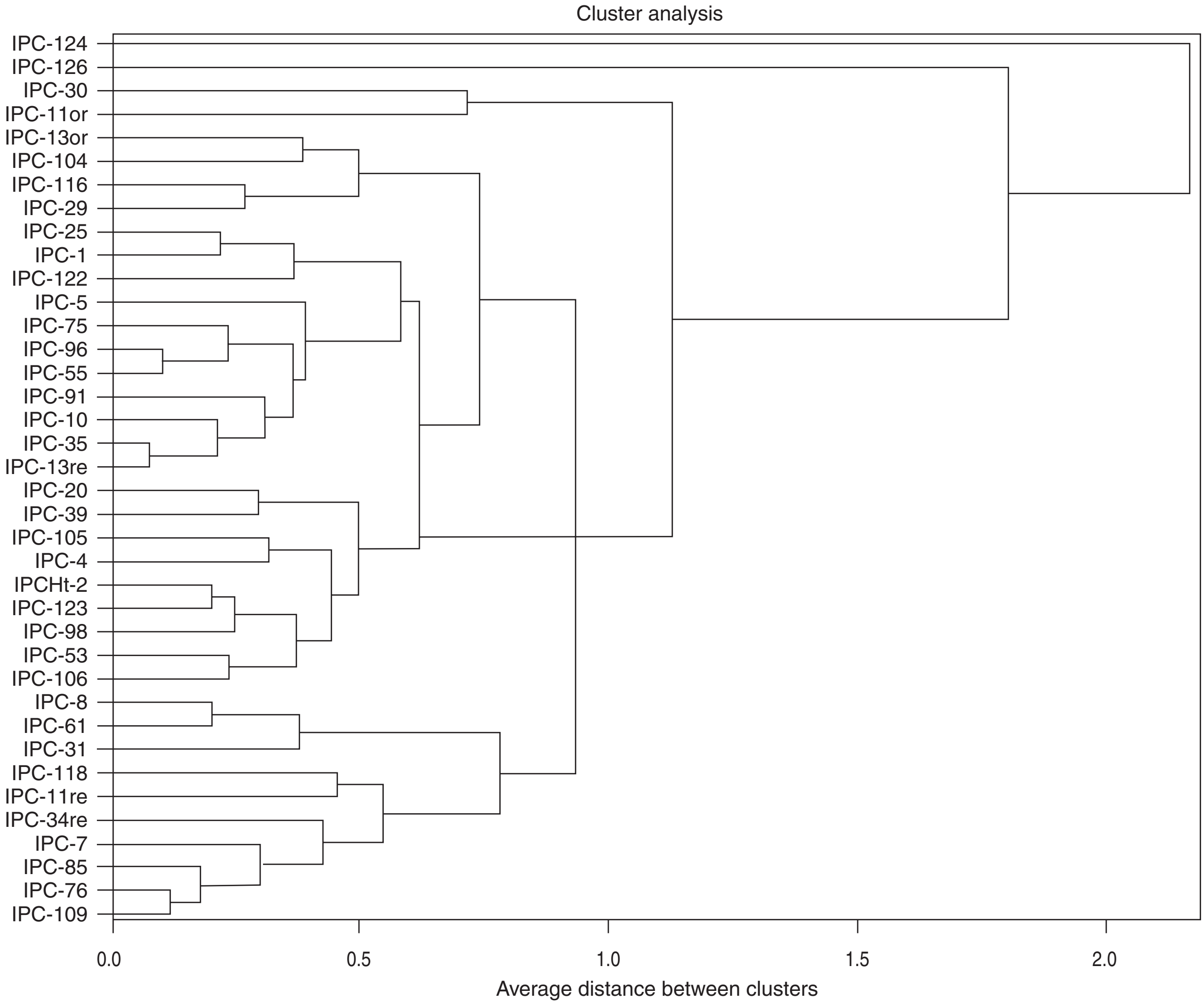

Fig 2 Cluster analysis of quality traits in tropical carrot inbreds

carotene content and distribution at harvest is influenced by genetic and climatic factors.

IPC-124, IPC-11red and IPC-13 orange were promising inbreds with high total carotenoids and can be utilized in the hybrid breeding programme in tropical carrot.

Cluster analysis of 38 inbreds based on 4 quantitative traits was performed by UPGMA method and a dendrogram was constructed as depicted in Fig 1. The inbreds were grouped into two clusters based on quantitative traits. Cluster I was the largest comprising 35 inbreds, followed by cluster II containing 3 inbreds. In cluster II, IPC 116 was quite diverse from rest of the two inbreds namely IPC 4 and IPC 8 which were quite similar. From the cluster it was observed that maximum distance (76.67) was between IPC-31 and IPC-85 and minimum (1.5) between IPC-61 and IPC-96 and IPC-5 & IPC-13 orange. On the basis of quality traits (total carotenoids, lycopene, TSS and moisture), three clusters were formed (Fig 2). Cluster III covers the maximum number of inbreds (36) while cluster I (IPC124) and II (IPC126) had only one each. This depicts that IPC 126, a dark purple black inbred and IPC 124, a red colour inbred are highly diverse. Similarly, maximum divergence was between IPC-124 and IPC-91 (10.50) whereas IPC-13 red and IPC-35 were very closely related with minimum distance of 0.37, followed by IPC-55 and IPC-96.

Based on the phenological data in Table 1, IPC-8 and IPC-4 were found best over the years for traits like plant weight, root weight, root length and root diameter. Similarly, the nutritional profile of the inbreds indicated that IPC-124, IPC-11red and IPC-13 orange were promising inbreds with high total carotenoids and can be utilized further in the breeding programme. IPC-126, a rich source of anthocyanin enriched dark purple black carrot can be effectively used for breeding of multinutrient and multicoloured carrot hybrids.

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