



Evaluation of quantitative and quality traits in diverse carrot (*Daucus carota*) genotypes to identify high-performing inbred lines for breeding programmes

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ABSTRACT

The study was carried out during the winter (*rabi*) season of 2021 and 2022 at Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Shalimar, Srinagar, Jammu and Kashmir to evaluate the quantitative and quality traits in diverse carrot (*Daucus carota* L.) genotypes and to identify high-performing inbred lines for breeding programmes. Fifty-two treatments comprising of 50 genotypes and 2 checks, procured from various sources were assessed for several quantitative and qualitative traits in augmented block design (ABD). The analysis of mean values revealed that no single genotype excelled in all the traits studied. However, certain genotypes demonstrated exceptional performance in specific economically significant traits. For instance, SKAU-C-5 showed superiority in plant height and petiole length, while SKAU-C-41 excelled in foliage length, root length, average root weight and root yield/ha. SKAU-C-48 stood out for traits such as the number of days to the first and last root harvest and SKAU-C-30 was notable for its high total carotenoid and anthocyanin content. Since no genotype exhibited outstanding performance across all traits, genotypes with the highest number of desirable characteristics could be utilized in a carefully designed hybridization programme to develop superior lines in subsequent segregating generations.

Keywords: Anthocyanin content, Carrot, Quality trait, Root yield, Total carotenoid content

As one of the most significant cool-season vegetable crops of the family Apiaceae, carrot (*Daucus carota* L.) is grown worldwide. Afghanistan is considered the primary centre of carrot diversity, followed by Turkey as the second centre (Stolarczyk and Janick 2011). In India, carrot cultivation covers 110 thousand ha, yielding 1,910 thousand metric tonnes annually, with an average productivity of 17.36 metric tonnes/ha. As per the 2024 report from the National Horticulture Board (NHB) and other sources, Haryana, West Bengal, Punjab, Uttar Pradesh, Madhya Pradesh and Bihar are the leading states in India for carrot cultivation. In the Union Territory of Jammu and Kashmir, carrot cultivation spans 1.86 thousand hectares, producing 32.32 thousand metric tonnes annually with an average productivity of 17.8 metric tonnes/ha (NHB 2023).

Carrot roots contain 88.3% moisture, an energy value

of 173.41 kJ/kcal and the following nutritional components per 100 g; 9.58 g carbohydrates, 2.80 g dietary fibre, 0.93 g protein, 4.74 g total sugars, including 3.59 g sucrose, 0.59 g glucose and 0.55 g fructose. They also contain 835 µg vitamin A, 8280 µg β-carotene, and 3480 µg α-carotene (Bjarnadottir 2019, Mozumder *et al.* 2019). Carotenoid content varies from 3.2–170 mg/kg and vitamin C ranges from 21–775 mg/kg across cultivars (Ahmad *et al.* 2019, Lone *et al.* 2025). Carrots are abundant in phytochemicals such as phenolics, carotenoids, polyacetylenes and ascorbic acid, which contribute to lowering the risk of cancer and cardiovascular diseases by exhibiting antioxidant, anti-inflammatory, lipid-modifying and anti-tumour properties (Ahmad *et al.* 2019).

The study aimed to evaluate carrot genotypes for traits such as plant height, root length, yield, carotenoid content, anthocyanin concentration and sugar composition. The selection of high-performing lines through tools like SPAD ensures stable, heritable traits, aligning with global trends to enhance nutritional and phytochemical profiles, addressing health-conscious consumer demands and supporting sustainable agricultural development (Santhi *et al.* 2015, Bjarnadottir 2019).

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MATERIALS AND METHODS

The study was carried out during the winter (*rabi*) season of 2021 and 2022 at Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Shalimar (34°0.14'N, 74°0.86'E; 1685 m amsl), Srinagar, Jammu and Kashmir. The region experiences a temperate climate characterized by mild summers and harsh winters. A total of 52 treatments, consisting of 50 genotypes and 2 check varieties selected from 297 germplasm lines obtained from Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir; different regions of Jammu and Kashmir (local germplasm); ICAR-National Bureau of Plant Genetic Resources, New Delhi; Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh and the Nordic Genetic Resource Centre in Sweden were evaluated for a range of quantitative and qualitative traits using an augmented block design. The seeds of these selected lines were planted with a spacing of 45 cm between ridges and 15 cm between plants along the ridges. Field maintenance and harvesting were conducted following the standard agricultural practices recommended by Sher-e-Kashmir University of Agricultural Sciences and Technology-Kashmir, Jammu and Kashmir.

Data was recorded for 10 quantitative traits, including plant height (cm), leaf length (cm), leaf width (cm), root length (cm), root diameter (cm), petiole length (cm), average root weight (g), days to first root harvest, days to last root harvest and root yield/ha (q). Additionally, observations were made on seven quality traits, including total carotenoids (mg/100 g), β-carotene content (mg/100 g), vitamin A content (mg/100 g), anthocyanin concentration (mg/100 g), reducing sugars (%), non-reducing sugars (%) and total soluble sugars (%). The mean values for all traits were calculated, and the collected data was analyzed using the statistical package for augmented design (SPAD) software, developed by ICAR-Indian Agricultural Statistics Research Institute, New Delhi.

RESULTS AND DISCUSSION

A wide range of variability was demonstrated by all the carrot genotypes involved in this study, for most of the quantitative and quality attributes (Table 1 and 2 and Supplementary Table 1) across both seasons, in individual and pooled data over seasons. The mean value estimations discovered that none of the genotype excelled in all the evaluated traits. Nevertheless, different genotypes were found to be

superior for distinct quality traits.

Based on the overall performance (pooled mean) of 1 various carrot genotypes, SKAU-C-5 (57.83), followed by SKAU-C-1 (50.91) and SKAU-C-19 (49.20), were superior for plant height (cm). For leaf length (cm), SKAU-C-41 (31.89) was the best-performing genotype, followed by SKAU-C-40 (31.79) and SKAU-C-19 (31.02). SKAU-C-3 (21.22) emerged superior for leaf width (cm), followed by SKAU-C-14 (20.52) and SKAU-C-19 (20.42). Regarding petiole length (cm), SKAU-C-5 (30.56) was the top performer, followed by SKAU-C-1 (29.00) and SKAU-C-9 (27.80).

Root traits revealed significant differences, viz. SKAU-C-41 (29.88) was superior in root length (cm), followed by SKAU-C-44 (29.38) and SKAU-C-21 (29.35). For root diameter (cm), SKAU-C-31 (4.79), SKAU-C-45 (4.72) and SKAU-C-11 (4.32) were the top genotypes. The average weight of roots (g) was highest in SKAU-C-41 (97.50), followed by SKAU-C-42 (95.50) and SKAU-C-46 (94.50).

The genotypes SKAU-C-27 (78.23 and 84.57) and SKAU-C-26 (79.57 and 85.91) demonstrated superior performance for days to first and last root harvest, respectively. The genotype SKAU-C-41 exhibited the highest root yield per hectare (406.25 q), followed by SKAU-C-42 (397.92) and SKAU-C-44 (390.98) (Supplementary Fig. 1).

For quality traits, SKAU-C-30 recorded the highest total carotenoid content (79.32 mg/100g), followed by SKAU-C-16 (79.12) and SKAU-C-18 (77.68). The β-carotene and vitamin A content (mg/100g) were highest in SKAU-C-10 (28.59 and 47.66), followed by SKAU-C-48 (28.00 and 46.66) and SKAU-C-12 (27.97 and 46.62) (Fig. 1). Anthocyanin content (mg/100g) was maximum in

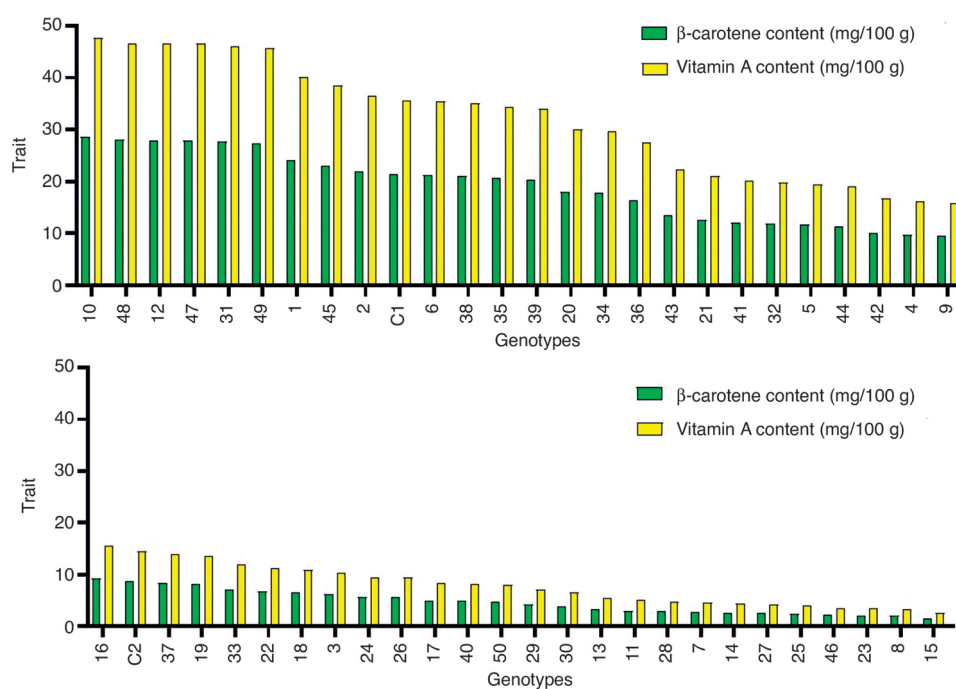


Fig. 1 Fifty-two diverse carrot genotypes for β-carotene content and vitamin A content (Pooled mean values).

Table 1 Comparative mean performance of different carrot genotypes for various quantitative traits during the *rab*i season 2021 (Y_1) and 2022 (Y_2)

S.No.	Genotype	Plant height (cm)		Root length (cm)		Root diameter (cm)		Average root weight (g)		Root yield/ha (q)								
		Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Pooled						
1.	SKAU-C-1	52.27	49.55	2.33	3.11	169.44	170.83	111.81	170.14	3.11	8.15	29.62	28.37	29.00	111.11	112.50	111.81	
2.	SKAU-C-2	36.27	33.58	3.01	2.23	287.50	288.89	288.20	2.23	2.57	21.22	11.35	21.65	20.40	21.03	169.44	170.83	170.14
3.	SKAU-C-3	36.24	33.55	3.35	2.57	141.67	143.06	142.37	2.57	2.73	13.89	21.22	18.85	17.60	18.23	287.50	288.89	288.20
4.	SKAU-C-4	48.66	48.47	3.51	2.73	241.67	243.06	242.37	2.73	3.18	13.89	13.89	27.13	28.38	27.76	141.67	143.06	142.37
5.	SKAU-C-5	57.92	57.73	4.05	3.27	119.44	120.83	120.14	3.27	3.18	8.85	8.85	29.93	31.18	30.56	241.67	243.06	242.37
6.	SKAU-C-6	41.35	41.16	2.40	3.18	137.50	138.89	138.20	3.18	2.56	9.62	15.09	21.67	22.92	22.30	119.44	120.83	120.14
7.	SKAU-C-7	46.29	46.10	1.77	2.56	134.72	136.11	135.42	2.56	2.58	16.62	16.62	17.30	18.55	17.93	134.72	136.11	135.42
8.	SKAU-C-8	38.95	41.64	1.80	2.58	195.83	197.22	196.53	2.58	3.18	13.45	13.45	27.17	28.42	27.80	195.83	197.22	196.53
9.	SKAU-C-9	41.89	44.58	2.40	3.18	111.11	112.50	111.81	3.18	2.71	12.49	12.49	16.67	17.92	17.30	111.11	112.50	111.81
10.	SKAU-C-10	34.69	37.38	1.93	2.71	245.83	247.22	246.53	2.71	4.71	15.02	15.02	22.35	21.10	21.73	245.83	247.22	246.53
11.	SKAU-C-11	46.20	46.39	3.93	4.71	93.06	94.44	93.75	4.71	3.05	13.72	13.72	28.18	26.93	27.56	93.06	94.44	93.75
12.	SKAU-C-12	47.33	47.52	2.27	3.05	309.72	311.11	310.42	3.05	3.95	15.65	15.65	17.12	15.87	16.50	309.72	311.11	310.42
13.	SKAU-C-13	43.98	41.29	3.17	3.95	355.56	356.94	356.25	3.95	3.50	20.52	20.52	19.92	18.67	19.30	355.56	356.94	356.25
14.	SKAU-C-14	46.81	44.12	4.28	3.50	315.28	316.67	315.98	3.50	3.90	18.12	18.12	17.45	16.20	16.83	315.28	316.67	315.98
15.	SKAU-C-15	43.71	41.02	4.68	3.90	375.00	376.39	375.70	3.90	3.10	12.92	12.92	18.18	16.93	17.56	375.00	376.39	375.70
16.	SKAU-C-16	37.00	37.19	3.88	3.10	297.22	298.61	297.92	3.10	3.00	16.52	16.52	13.28	12.03	12.66	297.22	298.61	297.92
17.	SKAU-C-17	36.10	36.29	3.78	3.00	322.22	323.61	322.92	3.00	2.93	13.35	13.35	14.58	13.33	13.96	322.22	323.61	322.92
18.	SKAU-C-18	39.40	36.71	3.71	2.93	354.17	355.56	354.87	2.93	3.91	20.42	20.42	18.45	17.20	17.83	354.17	355.56	354.87
19.	SKAU-C-19	49.10	49.29	3.13	3.91	226.39	227.78	227.09	3.91	4.51	14.35	14.35	20.05	18.80	19.43	226.39	227.78	227.09
20.	SKAU-C-20	47.07	47.26	3.73	4.51	215.28	216.67	215.98	4.51	3.47	19.82	19.82	23.55	22.30	22.93	215.28	216.67	215.98
21.	SKAU-C-21	47.47	47.66	4.25	3.47	312.50	313.89	313.20	3.47	3.17	15.15	15.15	25.68	24.43	25.06	312.50	313.89	313.20
22.	SKAU-C-22	47.73	47.92	3.95	3.17	131.94	133.33	132.64	3.17	4.08	13.72	13.72	12.22	10.97	11.60	125.00	126.39	125.70
23.	SKAU-C-23	32.03	32.22	3.08	2.30	125.00	126.39	125.70	2.30	3.82	12.79	12.79	14.08	12.83	13.46	252.78	254.17	253.48
24.	SKAU-C-24	31.60	31.79	3.30	4.08	252.78	254.17	253.48	4.08	4.31	15.32	15.32	17.28	16.03	16.66	197.22	198.61	197.92
25.	SKAU-C-25	34.47	31.78	4.50	3.82	197.22	198.61	197.92	3.82	4.45	13.52	13.52	9.33	10.58	9.96	293.06	294.44	293.75
26.	SKAU-C-26	37.30	34.61	3.53	4.31	293.06	294.44	293.75	4.31	3.75	14.79	14.79	23.03	24.28	23.66	331.94	333.33	332.64
27.	SKAU-C-27	30.09	29.90	3.67	4.45	331.94	333.33	332.64	4.45	3.07	13.69	13.69	15.23	16.48	15.86	194.44	195.83	195.14
28.	SKAU-C-28	48.45	48.26	2.97	3.75	194.44	195.83	195.14	3.75	3.07	240.28	240.28	241.67	240.98	240.98	240.98	240.98	240.98
29.	SKAU-C-29	35.69	35.50	3.85	3.07	240.28	241.67	240.98	3.07	3.85	240.98	240.98	241.67	240.98	240.98	240.98	240.98	240.98

Contd.

Table 1 (Concluded)

S.No.	Genotype	Plant height (cm)		Root length (cm)			Root diameter (cm)			Average root weight (g)			Root yield/ha (q)			
		Y ₁	Y ₂	Y ₁	Y ₂	111.11	112.50	111.81	Y ₂	Pooled	Y ₁	Y ₂	Pooled	Y ₁	Y ₂	Pooled
30.	SKAU-C-30	31.11	33.80	2.37	3.15	313.89	315.28	314.59	3.15	12.85	12.53	13.78	13.16	240.28	241.67	240.98
31.	SKAU-C-31	46.30	46.11	5.18	4.40	306.94	308.33	307.64	4.40	14.32	17.27	18.52	17.90	313.89	315.28	314.59
32.	SKAU-C-32	42.49	42.30	3.81	3.03	176.39	177.78	177.09	3.03	13.82	20.67	21.92	21.30	306.94	308.33	307.64
33.	SKAU-C-33	40.27	37.58	3.91	3.13	366.67	368.06	367.37	3.13	14.85	18.28	17.03	17.66	176.39	177.78	177.09
34.	SKAU-C-34	37.36	37.17	3.85	3.07	304.17	305.56	304.87	3.07	14.09	14.67	15.92	15.30	366.67	368.06	367.37
35.	SKAU-C-35	37.72	40.41	3.78	3.00	319.44	320.83	320.14	3.00	13.49	18.90	20.15	19.53	304.17	305.56	304.87
36.	SKAU-C-36	31.75	34.44	3.75	2.97	138.89	140.28	139.59	2.97	12.39	14.53	15.78	15.16	319.44	320.83	320.14
37.	SKAU-C-37	44.97	45.16	4.35	3.57	322.22	323.61	322.92	3.57	12.89	24.55	23.30	23.93	138.89	140.28	139.59
38.	SKAU-C-38	37.60	37.79	4.01	3.23	347.22	348.61	347.92	3.23	14.65	15.42	14.17	14.80	322.22	323.61	322.92
39.	SKAU-C-39	41.90	42.09	4.01	3.23	379.17	380.56	379.87	3.23	14.59	23.18	21.93	22.56	347.22	348.61	347.92
40.	SKAU-C-40	49.61	46.92	4.55	3.77	405.56	406.94	406.25	3.77	19.95	16.75	15.50	16.13	379.17	380.56	379.87
41.	SKAU-C-41	49.38	46.69	3.51	4.39	397.22	398.61	397.92	4.39	20.35	16.42	15.17	15.80	405.56	406.94	406.25
42.	SKAU-C-42	36.12	35.93	3.59	4.35	365.28	366.67	365.98	4.35	13.19	15.23	16.48	15.86	397.22	398.61	397.92
43.	SKAU-C-43	29.78	27.09	3.17	3.95	390.28	391.67	390.98	3.95	13.45	12.32	11.07	11.70	365.28	366.67	365.98
44.	SKAU-C-44	42.44	39.75	3.63	4.41	386.11	387.50	386.81	4.41	17.55	21.18	19.93	20.56	390.28	391.67	390.98
45.	SKAU-C-45	48.83	49.02	5.11	4.33	393.06	188.89	290.98	4.33	17.85	19.75	18.50	19.13	386.11	387.50	386.81
46.	SKAU-C-46	41.98	44.67	3.25	2.47	373.61	133.33	253.47	2.47	14.52	19.03	20.28	19.66	393.06	188.89	290.98
47.	SKAU-C-47	28.92	31.61	3.48	2.70	187.50	65.28	126.39	2.70	12.22	14.50	15.75	15.13	373.61	133.33	253.47
48.	SKAU-C-48	23.82	26.51	1.73	2.51	131.94	330.56	231.25	2.51	8.29	15.20	16.45	15.83	187.50	65.28	126.39
49.	SKAU-C-49	34.18	36.87	2.87	3.65	63.89	197.22	130.56	3.65	15.39	16.93	18.18	17.56	131.94	330.56	231.25
50.	SKAU-C-50	34.42	37.11	2.53	3.31	329.17	394.44	361.81	3.31	11.15	19.77	21.02	20.40	63.89	197.22	130.56
51.	CHECK-1	34.30	34.49	4.45	3.67	195.83	375.00	285.42	3.67	14.22	16.88	15.63	16.26	329.17	394.44	361.81
52.	CHECK-2	41.65	44.34	3.95	3.17	258.33	259.72	259.03	3.17	15.89	18.50	19.75	19.13	195.83	375.00	285.42
	Mean	40.44	40.35	3.48	3.40	4.146	4.103	4.125	3.40	14.48	18.85	18.71	18.79	258.33	259.72	259.03
	SEM	0.644	0.651	0.050	0.047	11.631	11.509	11.570	0.047	0.209	0.292	0.249	0.271	4.146	4.103	4.125
	CD (P=0.05)	1.807	1.825	0.139	0.133	15.392	15.230	15.311	0.133	0.587	0.819	0.699	0.759	11.631	11.509	11.570
	CD (P=0.01)	2.392	2.415	0.184	0.176	Y ₁	Y ₂	Pooled	0.176	0.777	1.084	0.925	1.005	15.392	15.230	15.311

Table 2 Comparative mean performance of different carrot genotypes for various quality traits

S.No.	Genotype	Total carotenoids (mg/100 g)	β -carotene (mg/100 g)	Vitamin A (mg/100 g)	Anthocyanin (mg/100 g)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)
1.	SKAU-C-1	37.60	24.05	40.09	219.35	6.71	2.10	4.61
2.	SKAU-C-2	26.52	21.89	36.49	15.68	8.53	2.41	6.12
3.	SKAU-C-3	8.72	6.21	10.34	144.09	8.54	2.75	5.79
4.	SKAU-C-4	10.92	9.68	16.13	32.69	8.50	2.72	5.79
5.	SKAU-C-5	13.40	11.67	19.44	15.68	8.55	2.41	6.15
6.	SKAU-C-6	28.72	21.22	35.37	27.29	5.22	2.57	2.66
7.	SKAU-C-7	9.40	2.76	4.59	54.18	7.56	2.03	5.54
8.	SKAU-C-8	4.52	2.04	3.39	89.00	4.09	0.75	3.33
9.	SKAU-C-9	9.60	9.48	15.80	104.89	8.57	2.75	5.82
10.	SKAU-C-10	14.24	28.59	47.66	40.12	7.75	1.72	6.03
11.	SKAU-C-11	8.52	3.03	5.05	247.76	8.49	1.80	6.68
12.	SKAU-C-12	10.00	27.97	46.62	21.18	6.54	2.18	4.36
13.	SKAU-C-13	18.44	3.33	5.54	161.10	8.54	2.42	6.12
14.	SKAU-C-14	16.96	2.66	4.43	26.58	8.37	2.57	5.80
15.	SKAU-C-15	4.96	1.61	2.69	129.23	8.48	2.41	6.07
16.	SKAU-C-16	79.12	9.33	15.55	21.18	6.51	2.19	4.32
17.	SKAU-C-17	5.08	5.01	8.36	254.89	6.30	2.25	4.05
18.	SKAU-C-18	77.68	6.58	10.96	250.92	7.32	1.74	5.58
19.	SKAU-C-19	10.12	8.14	13.57	13.04	4.57	2.71	1.86
20.	SKAU-C-20	19.96	18.05	30.08	108.35	7.26	1.82	5.44
21.	SKAU-C-21	14.24	12.66	21.10	86.05	7.88	2.73	5.15
22.	SKAU-C-22	8.04	6.80	11.34	90.94	8.57	2.74	5.83
23.	SKAU-C-23	12.68	2.06	3.43	139.00	8.50	2.72	5.78
24.	SKAU-C-24	13.04	5.63	9.39	54.99	7.88	2.74	5.13
25.	SKAU-C-25	11.56	2.41	4.01	244.50	7.91	2.74	5.17
26.	SKAU-C-26	8.16	5.63	9.39	32.18	8.21	2.65	5.56
27.	SKAU-C-27	3.56	2.58	4.30	32.28	7.89	2.71	5.19
28.	SKAU-C-28	77.52	2.93	4.88	56.01	6.50	2.22	4.28
29.	SKAU-C-29	5.72	4.27	7.12	88.90	7.01	2.36	4.64
30.	SKAU-C-30	79.32	3.92	6.54	255.91	6.67	1.70	4.97
31.	SKAU-C-31	28.32	27.68	46.13	146.44	7.21	2.13	5.08
32.	SKAU-C-32	13.72	11.89	19.82	128.21	8.20	2.08	6.12
33.	SKAU-C-33	10.60	7.17	11.96	69.65	7.12	2.07	5.05
34.	SKAU-C-34	20.76	17.77	29.62	44.81	7.23	0.51	6.72
35.	SKAU-C-35	23.44	20.68	34.46	112.02	7.50	2.03	5.47
36.	SKAU-C-36	19.08	16.48	27.47	81.37	6.99	2.09	4.90
37.	SKAU-C-37	10.28	8.36	13.94	70.37	7.43	0.93	6.51
38.	SKAU-C-38	22.56	21.02	35.04	156.52	7.45	2.15	5.30
39.	SKAU-C-39	22.52	20.40	34.01	37.98	7.55	2.06	5.49
40.	SKAU-C-40	17.68	4.91	8.19	180.86	7.21	1.86	5.35

Contd.

Table 2 (Concluded)

S.No.	Genotype	Total carotenoids (mg/100 g)	β -carotene (mg/100 g)	Vitamin A (mg/100 g)	Anthocyanin (mg/100 g)	Total sugars (%)	Reducing sugars (%)	Non-reducing sugars (%)
41.	SKAU-C-41	33.68	12.09	20.15	247.25	6.37	2.24	4.13
42.	SKAU-C-42	10.08	10.00	16.67	251.63	7.79	1.72	6.08
43.	SKAU-C-43	14.24	13.45	22.42	59.47	7.12	1.65	5.47
44.	SKAU-C-44	12.28	11.42	19.03	87.98	7.25	1.96	5.29
45.	SKAU-C-45	25.12	23.13	38.56	149.49	7.50	1.08	6.42
46.	SKAU-C-46	10.96	2.16	3.60	41.55	6.78	2.07	4.71
47.	SKAU-C-47	12.56	27.90	46.50	48.17	4.92	2.34	2.57
48.	SKAU-C-48	17.12	28.00	46.66	49.39	6.47	2.22	4.26
49.	SKAU-C-49	30.08	27.43	45.71	61.10	4.55	2.07	2.49
50.	SKAU-C-50	11.84	4.82	8.03	95.52	7.20	1.97	5.23
51.	CHECK-1	24.04	21.42	35.70	61.81	7.37	0.74	6.63
52.	CHECK-2	10.72	8.69	14.48	115.07	7.18	1.62	5.56
	Mean	20.19	11.91	19.84	102.97	7.27	2.10	5.17
	SEM	0.380	0.262	0.349	2.128	0.120	0.032	0.124
	CD ($P=0.05$)	1.067	0.734	0.978	5.968	0.336	0.089	0.349
	CD ($P=0.01$)	1.411	0.971	1.294	7.898	0.444	0.118	0.462

SKAU-C-30 (255.91), followed by SKAU-C-17 (254.89) and SKAU-C-42 (251.63) (Supplementary Fig. 2).

Regarding sugars, SKAU-C-9 (8.57) recorded the highest total sugars (%), closely followed by SKAU-C-22 (8.57) and SKAU-C-5 (8.55). For reducing sugars (%), SKAU-C-3 (2.75), SKAU-C-9 (2.75) and SKAU-C-22 (5.74) were the top genotypes. Non-reducing sugars (%) were highest in SKAU-C-34 (6.72), followed by SKAU-C-11 (6.68) and CHECK-1 (6.63).

Numerous studies have also documented a broad range of variability in quantitative and quality attributes among carrot genotypes and varieties, including Shin Kuroda, Early Nantes, Pusa Rudhira, Super Red, Pearl Red, Selection Red, Deep Red, Black Wonder and Dark Red. Santhi *et al.* (2015), Santhi and Priya (2016), Poleshi *et al.* (2018), Singh *et al.* (2019), Kumar and Nigam (2020), Kumar *et al.* (2021) and Kumar *et al.* (2022) have extensively reported on the variability across genotypes for traits like root length, root diameter, and carotenoid content.

Recent advancements in genetic analysis, such as those by Lone *et al.* (2025) and Ahmad *et al.* (2019), further emphasize the role of genetic diversity in enhancing agronomic and quality traits. Moreover, advancements in statistical tools like SPAD have significantly improved the precision of genotype evaluation under varied agro-climatic conditions, as noted by Kumar *et al.* (2023). These findings highlight the critical role of genotype selection in sustainable carrot breeding programmes and the development of varieties tailored to market and consumer preferences.

According to a general review of Table 1 and 2 on genotype performance, no genotype demonstrated improved performance for all the attributes. However, some genotypes

showed superior performance for some economically significant traits, including SKAU-C-5 for plant height and petiole length, SKAU-C-41 for leaf length, root length, average weight of roots and root yield/ha; SKAU-C-48 for days to first root harvest and days to last root harvest and SKAU-C-30 for total carotenoid content and anthocyanin content. The genotype with the greatest number of positive traits might be employed in a carefully designed hybridization program to choose higher performing lines in the succeeding segregating lines since no genotype could be found to have superior performance for all the characters.

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