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HORTICULTURAL STUDIES

RESEARCH PAPER

Screening of Nineteen Carrot Genotypes for Higher Growth, Yield, and Nutritional Quality

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Abstract

Carrot (*Daucus carota* L.) is an important root vegetable valued for yield, marketability, and nutritional quality. This study evaluated 19 carrot genotypes to identify promising materials for growth, yield, and pigment-related quality traits. Significant variation was observed among genotypes for all studied characters. Orange HYV produced the tallest plants (102.3 cm at 80 DAS), while Bankim Keshor recorded the highest number of leaves per plant (12.67 at 80 DAS). The longest roots were found in 21408B (21.8 cm), whereas Shidur had the maximum root diameter (5.1 cm). Pusha Keshor produced the highest individual root weight (165.41 g). King Kuroda showed superior agronomic performance, producing the highest gross yield (30.83 t ha^{-1}) and marketable yield (29.19 t ha^{-1}), with no cracked roots and a low percentage of branched roots. In contrast, 16´B114-1 showed the poorest yield performance. For nutritional quality, 21408B contained the highest β-carotene (1.252 mg 100 ml^{-1}), Bankim Keshor had the highest lycopene (0.334 mg 100 ml^{-1}), and New Kuroda showed the highest anthocyanin content (41 mg 100 g FW^{-1}). Overall, King Kuroda was the most promising genotype for yield and marketability, while 21408B, Bankim Keshor, and New Kuroda were promising for nutritional quality and should be further evaluated in multi-year and multi-location trials.

1. Introduction

Carrot (*Daucus carota*) is a nutritious root vegetable grown annually for edible purposes belonging to the Apiaceae (previously Umbelliferae) family, grown throughout the world. It is a well-known crop in the horticultural industry with high economic value and international recognition. Numerous elements, such as nutritional value, phytochemical composition, antioxidant potential, and health benefits, contribute to this (Leja et al., 2013). It is one of the world's top ten most important vegetable crops by market value and production regions (Sun et al., 2020). While carrots are often associated with the Mediterranean region, scientific evidence indicates that they originated in the area of Afghanistan and spread to the Mediterranean by the 10th to 12th centuries (Simon, 1993) and are grown in spring and summer in temperate regions and during winter in tropical and subtropical countries (Jaysawal et al., 2018).

Carrots are very versatile in colors such as orange, purple, white, yellow and red, and are used in a number of dishes and cultural cuisines across the globe (Sharma et al., 2012). Orange carrots are the richest source of β-carotene, which, when consumed, is converted into vitamin A, an essential component of eye health and immunity (Ellison et al., 2018; Heinonen, 1990). The carrot storage root is abundant in minerals, antioxidants, and dietary fiber, in addition to being a strong source of carotenoids, vitamins, and fiber (Arscott and Tanumihardjo, 2010).

Carrot is an important winter vegetable of Bangladesh with increasing popularity among consumers and high market value for farmers. According to the Bangladesh Bureau of Statistics (BBS), in the 2022-2023 period, Bangladesh produced 27,000 tons of carrots over 2,428 hectares, resulting in an average yield of 11.13 tons per hectare (BBS, 2024). This might be due to the lack of suitable high-yielding varieties. In addition, a significant number of carrots produced in Bangladesh are damaged due to improper handling and postharvest losses (Hassan, 2010). Carrot production can be a viable enterprise for most small-scale, resource-poor farmers, as carrots are short-duration crops and yield per unit area is high, making them profitable. In most developing countries, carrot yields per unit area remain below the recommended world average.

Two decades ago, the novelty of these high-yielding and readily cultivated crops led farmers across the country to adopt them as one of their preferred winter crops. However, there are slight variations in root quality and nutritional content across cultivars. Different carrot types may differ in root weight due to varietal differences, indicating that yields also depend on variety. In our country, seeds are mostly imported, which creates constraints for farmers to cultivate due to very high prices and limited availability. However, several local varieties could be a better substitute in this context. No work has been reported on the screening and scaling up of these local varieties, which can provide higher yield and quality production in Bangladesh.

For the cultivation of carrots, especially exotic, high-yielding varieties, farmers must rely on foreign seed supplies. Moreover, many popular exotic commercial carrot cultivars are hybrids, which are very expensive and not always available in time for sowing. Hence, cultivation of good quality carrots becomes uncertain every year, and the unavailability of quality seed restricts their production extensively. Therefore, this study aimed to identify the best genotypes that produce higher root yields with the highest nutrient content.

2. Material and Methods

2.1. Experimental site

The experiments were conducted at the Horticulture Farm of the Bangladesh Agricultural University, Mymensingh, and Postharvest Laboratory, Bangladesh Agricultural Research Institute (BARI), Gazipur from July 2023 to June 2024. The site of the field experiment is located between 24°75" N latitude and 90°50" E longitude. The elevation of the experimental area is approximately 18 meters above sea level.

2.2. Climate of the experimental site

The climate of the experimental area was subtropical, characterized by high temperatures, heavy rainfall, high humidity, and relatively long days from April to September, and low rainfall, moderate temperatures, low humidity, and short days during the rest of the year. Information regarding monthly maximum, minimum, and average temperature, relative humidity, rainfall, and average sunshine hours as recorded by the Weather Yard of Bangladesh Agricultural University, Mymensingh are shown in Table 1.

2.3. Characteristics of soil

The soil in the experimental area was sandy loam in texture and belonged to the Old Brahmaputra Flood Plains Alluvial Tract. The selected plot was highland, fertile, well-drained, and had a pH of 6.7. The nutrient condition of the selected plot was evaluated at the Department of Soil Science, Bangladesh Agricultural University, Mymensingh. The morphological characters of the soil of the experiment plots are given in Table 2.

2.4 Experimental treatment

The experiment was conducted as a single-factor study in which carrot genotype was the only

Table 1. Monthly average air temperature, relative humidity, total rainfall, and sunshine of the experimental site during the period from September 2023 to March 2024 (*: Monthly total, **: Monthly average).

Year	Month	**Air Temperature(°C)			**Relative humidity (%)	*Rainfall (mm)	*Sunshine (hours)
		Maximum	Minimum	Average			
2023	September	34.7	26.0	31.0	93.0	88.0	206.2
	October	32.7	19.0	27.0	83.7	78.0	205.9
	November	32.2	15.0	23.5	82.9	4.3	200.0
	December	28.5	9.0	18.7	86.8	0.0	117.9
2024	January	29.9	9.4	19.4	83.3	18.2	84.7
	February	31.2	11.0	21.1	80.1	8.4	137.8
	March	33.5	16.5	25.0	74.0	104.8	190.2

Source: Weather Yard, Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh.

Table 2. Soil analysis data of the experimental plot.

A. Morphological characteristics of the soil		
Morphological features	Characteristics	
Location	Horticultural Field, BAU, Mymensingh	
Soil tract	Old Brahmaputra Alluvium	
Soil series	Sonatola	
Parent materials	Non-calcareous, dark grey floodplain	
Agro-ecological zone	Brahmaputra River-Borne deposits, Old Brahmaputra Floodplain (AEZ-9)	
Topography	Fairly level	
Drainage	Moderate	
B. Physical characteristics of the soil		
Constituents	Percentage	
Sand (0.2-0.02 mm)	35.40%	
Silt (0.02-0.002 mm)	62.62%	
Clay (<0.002 mm)	06.15%	
Textural class	Silt loam	
C. Chemical characteristics of the soil		
Soil properties	Analytical data	Critical level
pH	6.81	
Organic carbon (C)	0.89%	
Total Nitrogen (N)	0.16%	
Available phosphorus (P)	22 ppm	8.00
Available potassium (K)	0.09 me 100 g^{-1} soil	0.15
Available zinc (Zn)	68 ppm	8.00
Available boron (B)	1.10 ppm	1.15
Available sulfur (S)	0.20 ppm	0.21
Soil pH	06.700	--
Organic carbon (%)	00.860	--
Total nitrogen (%)	00.160	00.12
Available phosphorus (ppm)	17.050	10.00
Available potassium (me 100 g^{-1} soil)	00.100	00.15

Source: Agrivarsity Humboldt Soil Testing Laboratory, Department of Soil Science, Bangladesh Agricultural University, Mymensingh.

factor under investigation. A total of 19 genotypes were included: G1 (Kuroda), G2 (New Kuroda), G3 (Kuroda 35), G4 (King Kuroda), G5 (Shin Kuroda), G6 (Kuroda Improved), G7 (Shidur), G8 (Pusha Keshor), G9 (Bankim Keshor), G10 (Orange HYV), G11 (Brasilia 2007), G12 (BAU Gazor 5), G13 (Brasilia Agroflora), G14 (Prima Agroflora), G15 (Gazor Lovely), G16 (Autumn King 2), G17 (Nantes 5), G18 (16´B114-1), and G19 (21408B).

2.5. Land preparation

The experimental field was prepared for planting carrot seeds on 15 October 2023 using a power tiller. All the weeds and stubble were collected and removed from the land. It was then exposed to sunlight for 7 days before the next ploughing. Then the land was ploughed and cross-ploughed to obtain good tilth. According to the experimental design, the experimental plot was ultimately divided into unit plots. Plots were surrounded by planned drainage and irrigation channels.

2.6. Application of manure and fertilizer

The experimental plots were treated with recommended doses of NPKS fertilizers. The whole dose of Phosphorus (P) and Sulfur (S) fertilizers and half dose of Potassium (K) fertilizer were applied during final land preparation, whereas Nitrogen (N) fertilizer was applied in three installments at 30, 45, and 60 days after sowing of carrot seeds. The remaining dose of K fertilizer was applied at 45 days after seed sowing.

2.7. Design and layout of the experiment

To evaluate carrot genotypes, a field experiment was conducted at Bangladesh Agricultural University (BAU) during November 2023 to January 2024. A total of 19 carrot genotypes (Figure 1) were grown for root production under field conditions. The experiment followed a single-factor Randomized Complete Block Design (RCBD) with three replications, resulting in 57 unit plots (19 genotypes × 3 replications). Each unit plot measured 1 m × 1 m (1 m^2), and seeds were sown in rows maintaining a spacing of 25 cm between rows and 10 cm between plants. A distance of 1 m was maintained between blocks, while adjacent unit plots were separated by 50 cm to facilitate intercultural operations. Nutritional analyses were carried out at the Postharvest Laboratory, Bangladesh Agricultural Research Institute (BARI), Gazipur, from January to March 2024. Laboratory experiments followed a Completely Randomized Design (CRD) with three replications. Carotenoid, anthocyanin, and lycopene contents were determined using standard spectrophotometric methods.

2.8. Field preparation and seed sowing

Before sowing, the seeds were soaked in water for 24 hours and then wrapped in a thin cloth. To dry

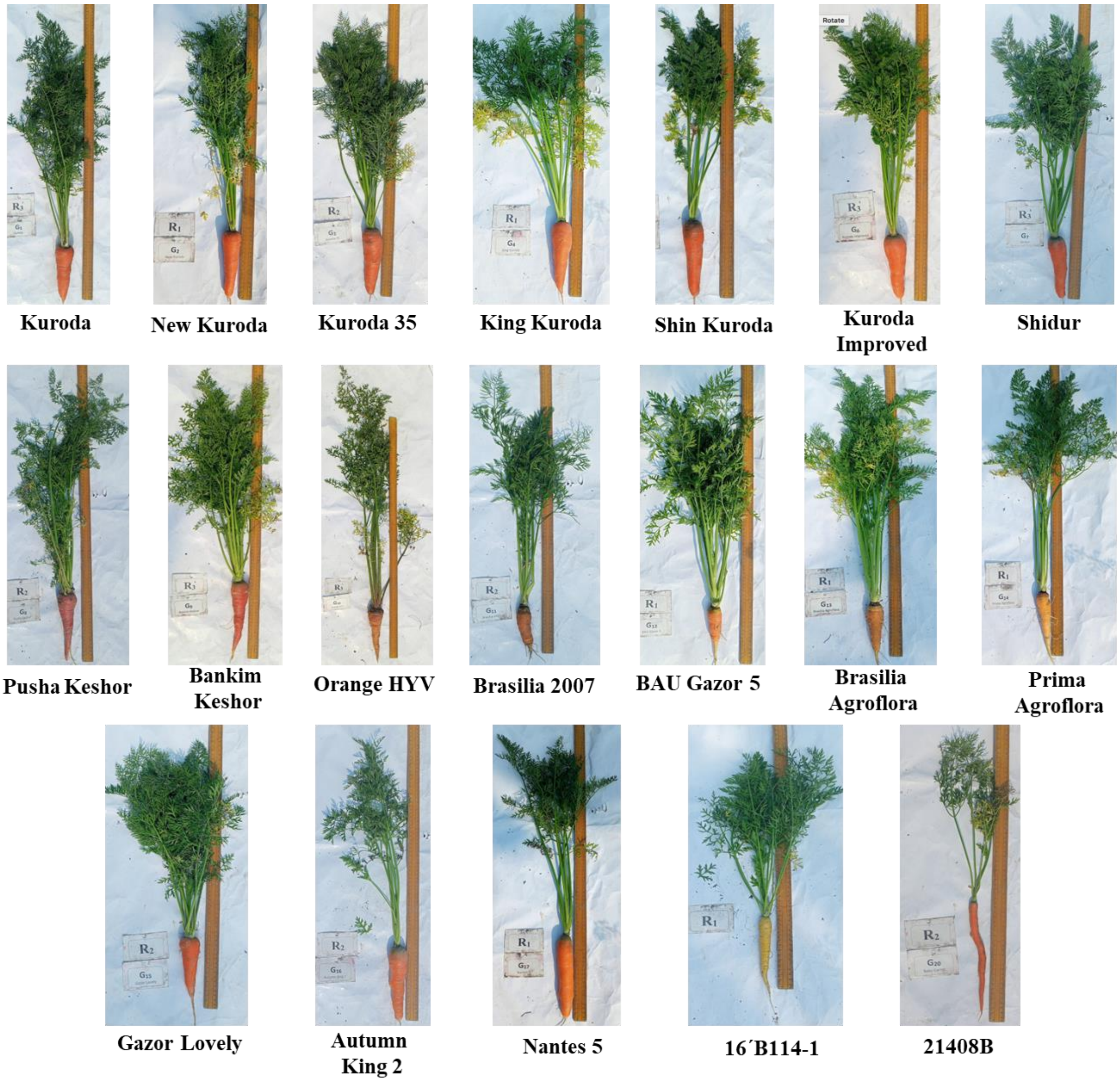

Figure 1. Carrot genotypes used in the study (G1=Kuroda, G2=New Kuroda, G3=Kuroda 35, G4=King Kuroda, G5=Shin Kuroda, 4 G6=Kuroda improved, G7=Shidur, G8=Pusha keshor, G9=Bankim keshor, G10=Orange 5 HYV, G11=Brasilia 2007, G12=BAU Gazor 5, G13=Brasilia Agroflora, G14=Prima Agroflora, 6 G15=Gazor lovely, G16=Autumn King 2, G17= Nantes 5, G18=16'B114-1, G19=21408B).

the surface water, the moistened seeds were spread onto polythene sheets for 2 hours. This operation was performed to facilitate rapid seed germination. The soaked seeds were sown in lines in the field at a depth of 1.5 cm. Each plot contained three lines, with a spacing of 25 cm between lines and a plant-to-plant spacing of 10 cm. The date of sowing was 1 November 2023, and the soil was covered immediately after sowing. Banana leaves were spread throughout the plot to conserve soil moisture and create a dark environment for seed germination.

2.9. Intercultural operation

Immediately after sowing, light irrigation was applied, followed by mulching with dried banana leaves to conserve soil moisture. The mulch was maintained for approximately one week and then was removed after seedling emergence to facilitate proper growth. Seedling emergence was completed within 10 days after sowing. Thinning was carried out three times to remove overcrowded seedlings, with final thinning at 15 days after sowing (DAS) to maintain a spacing of 25 cm between rows and 10 cm between plants.

Irrigation was continued throughout the crop growth period, with subsequent applications at 15, 30, 45, 55, and 75 DAS.

Weeding was performed as needed during the entire growth period to maintain a weed-free environment, improve soil aeration, and prevent soil crust formation.

No major diseases were observed in the field, and no fungicides were applied. However, mole crickets and cutworms were observed during the early seedling stage and were controlled by spraying Pyriphos at 14, 21, and 28 DAS.

2.10. Harvesting

After 85 days of sowing, the crop was harvested for data collection when the foliage had turned pale yellow. From each unit plot, ten randomly chosen plants were taken from each plot, and the remaining portion of the plot was also harvested for data collection. Harvesting was performed extremely gently with a spade. Next, the soil and fibrous roots clinging to the tap roots were removed.

2.11. Parameters measured

In the field area, the observations were recorded from the 40th day after sowing seeds and giving at 10-day intervals until harvesting of carrots (80 DAS). During this time, the plant height (cm), and number of leaves were taken. At harvest, the total number of roots per plot, the percentage of cracked and branched roots, root length (cm), root diameter (cm), and root weight (g), yield per plot (g), yield (t ha^{-1}) and marketable root yield (t ha^{-1}) were recorded for subsequent calculations. For nutritional content measurements, representative samples were collected in the BARI postharvest laboratory, where β-carotene, anthocyanin, and lycopene contents were determined.

2.12 Measurement of β-carotene and lycopene content

Before sampling, the roots were washed properly. A fresh sample of carrots was homogenized with a pestle and mortar. Sixteen ml of acetone-hexane (2:3) solvent was added to 1.0 g of the proper homogenate and mixed in a test tube. The test tube was then centrifuged for 5 min at 4000 rpm. Two phases are separated and supernatant was taken in another test tube. Finally, supernatant was taken in a cuvette and optical density was measured at 663, 645, 505, and 453 nm in a spectrophotometer, using hexane solvent as a blank. β-carotene (mg 100 ml^{-1} of extract) and lycopene (mg 100 ml^{-1} of extract) were calculated according to the formula given by Nagata and Yamashita (1992).

$$\beta\ carotene = 0.216 \times A_{663} - 1.22 \times A_{645} - 0.304 \times A_{505} + 0.452 \times A_{453}$$

$$Lycopene = -0.0458 \times A_{663} - 0.204 \times A_{645} - 0.372 \times A_{505} + 0.806 \times A_{453}$$

2.13. Measurement of anthocyanin content

100 g of fresh carrot was homogenized with an equal volume of distilled water. The homogenate (10 g) was mixed with 100 ml of distilled water and with 70% (v/v) ethanol aqueous solution. The distilled water and 70% ethanol aqueous solution were acidified to pH 3 with sulfuric acid using a pH meter (Seven Compact, Japan). The mixtures were then incubated in a 600°C water bath under stirring for 4 hours, followed by centrifugation at 1440 × g for 15 min (Himac CT6E, Japan). The supernatant was collected for analysis. Anthocyanin content (AC) was determined by the pH differential method. Briefly, a sample solution was diluted in two buffers (pH 1.0 and 4.5) and then measured at 520 and 700 nm using a spectrophotometer (Jasco V-750, Japan). Anthocyanin content (mg 100 g FW^{-1}) was calculated according to the following formula used by (Xie et al., 2019).

$$Anthocyanin = (A_{520} - A_{700})\ pH1.0 - (A_{520} - A_{700})pH4.5$$

2.14. Statistical analysis

The field experiment was conducted following a RCBD with three replications, while the laboratory experiment was arranged in a CRD with three replications. These experimental designs formed the basis for the statistical analyses.

All collected data were analyzed using the R statistical software. Analysis of variance (ANOVA) was performed using the F-test to determine the significance of treatment effects. Mean comparisons were conducted using Tukey's Honest Significant Difference (HSD) test for mean separation and lettering.

3. Results and Discusssion

3.1. Plant height (cm)

The plant height of the carrot plants was measured at 40, 50, 60, 70, and 80 days after sowing seeds. There was a statistically significant difference across the carrot varieties. The highest plant height was observed in the G10 (Orange HYV) genotype, at 29.6 cm at 40 DAS and 102.3 cm at 80 DAS, just before harvesting. Immediately after G10, G9 (Bankim Keshor) showed the highest plant height, 81.2 cm.

On the contrary, the lowest plant height was found in the G16 (Autumn King 2) at the 40 DAS which was 14.5 cm and after that, the lowest plant height was observed in G19 (21408B) which was 22.5 cm, 29.5 cm, 38.0 cm, and 49.2 cm at 50, 60, 70, and 80 DAS, respectively. The variations in the plant height might be due to the varietal characters and it's shown in Table 3.

3.2. Number of leaves per plant of carrot

Significant variation was observed in the number of leaves per plant. The number of leaves per plant was another parameter analyzed in this experiment and is presented in Table 4. This was also measured at 40, 50, 60, 70, and 80 days after sowing. Five representative plant leaves were selected, and the mean data were used for the

Table 3. Effect of genotypes on the plant height of carrot.

Genotypes	Plant height				
	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS
G1	20.2 ^{bcde}	32.8 ^{bc}	47.2 ^{bcd}	57.2 ^{bcde}	66.9 ^{efg}
G2	19.3 ^{bcde}	29.3 ^{bcde}	42.8 ^{cd}	52.6 ^{def}	63.7 ^{gh}
G3	23.6 ^{abc}	35.0 ^{bc}	50.4 ^{bc}	63.8 ^{bcd}	70.2 ^{cde}
G4	22.3 ^{abcd}	35.2 ^{bc}	48.5 ^{bc}	60.4 ^{bcde}	69.7 ^{cde}
G5	23.2 ^{abcd}	34.3 ^{bc}	47.2 ^{bcd}	59.2 ^{bcde}	67.6 ^{defg}
G6	19.3 ^{bcde}	33.3 ^{bc}	47.6 ^{bcd}	54.0 ^{cde}	65.0 ^{fgh}
G7	20.5 ^{bcde}	31.3 ^{bcde}	44.8 ^{bcd}	56.3 ^{bcde}	68.3 ^{defg}
G8	25.0 ^{ab}	38.5 ^{b}	56.4 ^{b}	69.7 ^{bc}	79.2 ^{b}
G9	24.0 ^{abc}	37.1 ^{bc}	56.0 ^{b}	70.5 ^{b}	81.2 ^{b}
G10	29.6 ^{a}	49.0 ^{a}	70.6 ^{a}	89.5 ^{a}	102.3 ^{a}
G11	21.9 ^{bcd}	32.1 ^{bcd}	48.5 ^{bc}	61.7 ^{bcde}	73.4 ^{c}
G12	21.5 ^{bcde}	31.8 ^{bcde}	47.2 ^{bcd}	58.5 ^{bcde}	67.9 ^{defg}
G13	23.6 ^{abc}	31.3 ^{bcde}	47.1 ^{bcd}	61.5 ^{bcde}	72.1 ^{cd}
G14	22.6 ^{abcd}	30.6 ^{bcde}	48.6 ^{bc}	60.2 ^{bcde}	68.5 ^{def}
G15	18.0 ^{bcde}	28.6 ^{cde}	40.0 ^{cde}	49.1 ^{def}	61.7 ^{hi}
G16	14.5 ^{e}	22.8 ^{de}	36.2 ^{de}	48.1 ^{def}	60.3 ^{hi}
G17	18.8 ^{bcde}	28.7 ^{cde}	42.2 ^{cd}	51.1 ^{def}	60.9 ^{hi}
G18	17.0 ^{cde}	28.3 ^{cde}	36.5 ^{de}	47.0 ^{ef}	58.4 ^{i}
G19	16.0 ^{de}	22.5 ^{e}	29.5 ^{e}	38.0 ^{f}	49.2 ^{j}
LSD$_{0.05}$	3.67	4.66	5.69	7.75	2.47
LSD$_{0.01}$	4.91	6.29	7.69	10.48	3.34
Level of significance	**	**	**	**	**

Source of variation	df	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS
Genotypes		37.756**	100.721**	228.650**	359.379**	356.662**
Error	36	4.954	8.127	12.147	22.528	2.288
Total	56					

** = Significant at 1% level of probability. (G1=Kuroda, G2=New Kuroda, G3=Kuroda 35, G4=King Kuroda, G5=Shin Kuroda, 4 G6=Kuroda Improved, G7=Shidur, G8=Pusha Keshor, G9=Bankim Keshor, G10=Orange 5 HYV, G11=Brasilia 2007, G12=BAU Gazor 5, G13=Brasilia Agroflora, G14=Prima Agroflora, 6 G15=Gazor lovely, G16=Autumn King 2, G17= Nantes 5, G18=16'B114-1, G19=21408B).

Table 4. Effect of genotypes on the number of leaves per plant of carrot.

Genotypes	Number of leaves per plant				
	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS
G1	3.86 ^{ab}	4.18 ^{ab}	6.86 ^{ab}	8.13 ^{abc}	9.01 ^{b}
G2	4.06 ^{ab}	4.21 ^{ab}	7.26 ^{ab}	8.68 ^{abc}	9.00 ^{b}
G3	4.40 ^{ab}	4.80 ^{ab}	7.06 ^{ab}	7.58 ^{abc}	9.45 ^{b}
G4	4.00 ^{ab}	4.43 ^{ab}	7.48 ^{ab}	7.70 ^{abc}	8.90 ^{b}
G5	4.00 ^{ab}	4.13 ^{ab}	6.76 ^{ab}	7.70 ^{abc}	9.24 ^{b}
G6	4.13 ^{ab}	4.13 ^{ab}	6.53 ^{ab}	7.35 ^{abc}	9.21 ^{b}
G7	4.66 ^{a}	5.05 ^{a}	9.13 ^{a}	10.87 ^{a}	8.98 ^{b}
G8	4.55 ^{ab}	4.77 ^{ab}	9.61 ^{a}	11.03 ^{a}	11.37 ^{a}
G9	4.06 ^{ab}	4.01 ^{ab}	6.02 ^{ab}	5.93 ^{bc}	12.67 ^{a}
G10	4.16 ^{ab}	4.84 ^{ab}	7.96 ^{ab}	8.63 ^{abc}	7.21 ^{c}
G11	4.00 ^{ab}	4.16 ^{ab}	8.05 ^{ab}	10.33 ^{ab}	9.78 ^{b}
G12	3.80 ^{ab}	4.19 ^{ab}	6.45 ^{ab}	7.41 ^{abc}	11.40 ^{a}
G13	3.93 ^{ab}	3.91 ^{ab}	7.00 ^{ab}	8.31 ^{abc}	9.11 ^{b}
G14	4.05 ^{ab}	4.22 ^{ab}	8.19 ^{ab}	8.25 ^{abc}	9.67 ^{b}
G15	3.77 ^{ab}	3.60 ^{b}	6.70 ^{ab}	7.61 ^{abc}	9.23 ^{b}
G16	3.63 ^{b}	4.10 ^{ab}	6.46 ^{ab}	7.03 ^{abc}	9.11 ^{b}
G17	4.00 ^{ab}	4.33 ^{ab}	7.00 ^{ab}	8.00 ^{abc}	8.98 ^{b}
G18	3.68 ^{ab}	3.62 ^{b}	5.26^{b}	5.64 ^{c}	9.62 ^{b}
G19	3.86 ^{ab}	4.18 ^{ab}	6.867 ^{ab}	8.13 ^{abc}	6.98 ^{c}
LSD$_{0.05}$	0.50	0.64	1.89	2.17	0.83
LSD$_{0.01}$	0.67	0.86	2.53	2.93	1.12
Level of significance	**	**	**	**	**

Source of variation	df	40 DAS	50 DAS	60 DAS	70 DAS	80 DAS
Genotypes	18	0.23548**	0.44373**	3.2057**	5.9463**	5.1082**
Error	36	0.09264	0.15144	1.3175	1.7618	0.2590
Total	56					

** = Significant at 1% level of probability. (G1=Kuroda, G2=New Kuroda, G3=Kuroda 35, G4=King Kuroda, G5=Shin Kuroda, 4 G6=Kuroda Improved, G7=Shidur, G8=Pusha Keshor, G9=Bankim Keshor, G10=Orange 5 HYV, G11=Brasilia 2007, G12=BAU Gazor 5, G13=Brasilia Agroflora, G14=Prima Agroflora, 6 G15=Gazor lovely, G16=Autumn King 2, G17= Nantes 5, G18=16'B114-1, G19=21408B).

findings. Here, the highest number of leaves was measured in G7 (Shidur) for the 40 and 50 DAS which were 4.66 and 5.05 respectively but after 60, and 70 DAS the number of leaves was the highest in G8 (Pusha keshor) which was 9.61 and 11.03, and after 80 DAS the number of leaves was the highest in G9 (Bankim keshor). On the other hand, at 40 DAS the lowest number of leaves was observed in G16 (Autumn King) which was 3.63 and then the following days the lowest number of leaves was seen in G15 (Gazor lovely) which were 3.60 at 50 DAS, in G18 (16'B114-1) 5.26 at 60 DAS, 5.64 at 70 DAS and in G19 (21408B) in 6.98 at 80 DAS.

3.3. Yield and yield contributing characters

3.3.1. Root length (cm)

The length of carrot was found to be statistically significant. The highest length was found in G19 (21408B) which was 21.8 cm followed by G8 Pusha Keshor (21.6 cm), G9=Bankim Keshor (20.6 cm), G10=Orange HYV (19.0 cm) and lowest length was observed in G11=Brasilia Agroflora (12.4 cm).

3.3.2. Root diameter (cm)

Significant variation in root diameter was observed among genotypes. The highest diameter was in G7=Shidur (5.1 cm) followed by G5=Shin Kuroda (4.8 cm), G1=(Kuroda) and G8=Pusha Keshor (4.7 cm) and the lowest diameter was found in G19=21408B (1.7 cm).

3.3.3. Individual root weight (g)

Different genotypes exhibited a significant variation in the fresh weight of individual roots. The highest individual root weight was observed in G8=Pusha Keshor (165.41 g) followed by G3=Kuroda 35 (160.20 g) and G10=Orange HYV (147.16 g).

3.3.4. Branched and cracked root per plot (%)

The percentage of branched roots and cracked root production was significantly influenced by the different genotypes. Branched and cracked roots were found in various genotypes. The highest cracked roots were found in G10=Orange HYV (7.72%) and a total of 11 genotypes (G1, G2, G3, G6, G11, G12, G13, G14, G16, and G18) bear no cracked roots. In the case of branched root, the highest value was observed in G1 (Kuroda, 15.1%), followed by G12 (BAU Gazor 5, 14.04%), and the lowest was in G7 (Shidur, 3.88%).

3.3.5. Yield per plot (kg)

The usage of several types of carrots resulted in considerable differences in root production. The maximum yield (3.08 kg) was observed in King Kuroda followed by Shin Kuroda (2.84 kg) and the lowest yield (0.41 kg) was found in 16'B114-1.

3.3.6. Yield (t ha^{-1})

The variation due to the effect of different genotypes in respect of gross yield of roots t ha^{-1} was highly significant. The highest yield was recorded in G4 (King Kuroda) which was 30.83 t ha^{-1} followed by G2=New Kuroda (28.40 t ha^{-1}) and the lowest was in G18 (16´B114-1) which was 4.13 t ha^{-1}.

3.3.7. Marketable yield (t ha^{-1})

The variation due to the effect of different genotypes in respect of marketable yield of roots ton per hectare was significant. Considering the edible root the highest marketable yield (29.19 t ha^{-1}) was also in G4=King Kuroda and the lowest (3.82 t ha^{-1}) was in G18=16´B114-1. Comparing all these genotypes it can be concluded that G4=King Kuroda genotype gave the largest amount of yield, there was no cracked root found and the percentage of branched root was also low (5.26%). On the other hand, though there was no cracked root in G18 (16´B114-1) but the production of this genotype was lower than all other genotypes. All this data is presented in Table 5.

3.4. β carotene content (mg 100 ml^{-1})

The β-carotene content of different genotypes is significantly influenced. In the analysis, the highest β-carotene content (mg 100 ml^{-1} of extract) was observed in G19 (21408B; 1.252), and the lowest was in G14 (Prima Agroflora; 0.084 mg 100 ml^{-1} of extract). These values are shown in Table 6.

3.5. Lycopene content (mg 100 ml^{-1})

Another important organic pigment, named lycopene, was also analyzed and found to be significantly influenced. The highest value was observed in G9 (Bankim Keshor; 0.335 mg 100 ml^{-1} of extract), and the lowest in G15 (Gazor Lovely; 0.002 mg 100 ml^{-1} of extract) (Table 6).

3.6. Anthocyanin content (mg 100 g FW^{-1})

Anthocyanin content was included as a biochemical quality parameter to assess possible genotypic variation in flavonoid pigmentation, even where visible purple or red coloration was not clearly expressed, since external root color alone may not fully reflect the presence or concentration of anthocyanin compounds. The anthocyanin content was significantly influenced by the different genotypes. The highest amount of anthocyanin was observed in G2 (New Kuroda), which was 41 mg 100 g FW^{-1}, and the lowest was 0.03 mg 100 g FW^{-1} in G17 (Nantes 5).

Table 5. Effect of genotypes on yield and yield contributing characters of carrot.

Genotypes	%Cracked root	%Branched root	Root length (cm)	Root diameter (cm)	Individual wt of roots	Yield/plot (g)	Yield (t ha^{-1})	Marketable root (t ha^{-1})
G1	0.000 ^{a}	15.10 ^{a}	15.67 ^{cdefg}	4.733 ^{ab}	128.31 ^{bc}	2.700 ^{abc}	27.00 ^{abc}	22.91 ^{ab}
G2	0.000 ^{a}	5.87 ^{cde}	16.93 ^{bcdef}	4.147 ^{bcdef}	92.33 ^{d}	2.840 ^{ab}	28.40 ^{ab}	26.74 ^{a}
G3	4.897 ^{a}	7.64 ^{abcde}	18.73 ^{abcd}	4.553 ^{ab}	160.20 ^{a}	2.627 ^{abc}	26.27 ^{abc}	23.02 ^{ab}
G4	0.000 ^{a}	5.26 ^{de}	18.25 ^{abcd}	4.700 ^{ab}	135.39 ^{bc}	3.083 ^{a}	30.83 ^{a}	29.19 ^{a}
G5	0.000 ^{a}	5.96 ^{bcde}	17.40 ^{bcde}	4.847 ^{ab}	126.98 ^{bc}	2.817 ^{ab}	28.17 ^{ab}	26.49 ^{a}
G6	3.030 ^{a}	13.64 ^{ab}	16.24 ^{cdefg}	4.180 ^{bcdef}	113.60 ^{cd}	2.337 ^{bc}	23.37 ^{bc}	19.41 ^{bc}
G7	2.568 ^{a}	3.88 ^{e}	16.80 ^{bcdef}	5.127 ^{a}	100.49 ^{d}	2.667 ^{abc}	26.67 ^{abc}	24.98 ^{ab}
G8	7.057 ^{a}	9.04 ^{abcde}	21.65 ^{a}	4.733 ^{ab}	165.41 ^{a}	2.327 ^{bc}	23.27 ^{bc}	19.53 ^{bc}
G9	2.743 ^{a}	11.83 ^{abcd}	20.67 ^{ab}	4.333 ^{abcde}	137.01 ^{b}	1.463 ^{de}	14.63 ^{de}	12.48 ^{def}
G10	7.723 ^{a}	13.48 ^{abc}	19.00 ^{abc}	4.480 ^{abc}	147.16 ^{ab}	1.397 ^{def}	13.97 ^{def}	10.96 ^{ef}
G11	0.000 ^{a}	8.18 ^{abcde}	12.60 ^{g}	3.500 ^{ef}	63.24 ^{e}	1.247 ^{efg}	12.47 ^{efg}	11.52 ^{ef}
G12	0.000 ^{a}	14.04 ^{a}	14.08 ^{efg}	3.575 ^{def}	56.66 ^{e}	0.717 ^{fgh}	7.17 ^{fgh}	6.16 ^{fg}
G13	0.000 ^{a}	4.17 ^{de}	12.42 ^{g}	3.708 ^{cdef}	65.50 ^{e}	0.907 ^{efgh}	9.07 ^{efgh}	8.62 ^{efg}
G14	0.000 ^{a}	11.32 ^{abcde}	13.15 ^{fg}	3.433 ^{f}	56.95 ^{e}	1.023 ^{efgh}	10.23 ^{efgh}	9.07 ^{efg}
G15	2.500 ^{a}	11.49 ^{abcde}	16.28 ^{cdefg}	4.633 ^{ab}	135.62 ^{bc}	1.347 ^{ef}	13.47 ^{ef}	11.59 ^{ef}
G16	0.000 ^{a}	10.16 ^{abcde}	16.20 ^{cdefg}	4.400 ^{abcd}	95.81 ^{d}	1.463 ^{de}	14.63 ^{de}	13.15 ^{cde}
G17	1.449 ^{a}	9.10 ^{abcde}	18.27 ^{abcd}	4.567 ^{ab}	100.53 ^{d}	2.057 ^{cd}	20.57 ^{cd}	18.45 ^{bcd}
G18	0.000 ^{a}	7.56 ^{abcde}	14.67 ^{defg}	2.320 ^{g}	32.76 ^{f}	0.413 ^{h}	4.13 ^{h}	3.82 ^{g}
G19	0.000 ^{a}	10.12 ^{abcde}	21.80 ^{a}	1.753 ^{g}	27.07 ^{f}	0.653 ^{gh}	6.53 ^{gh}	5.88 ^{fg}
$LSD_{0.05}$	4.61	4.15	24.12	11.72	2.16	0.44	0.06	0.37
$LSD_{0.01}$	6.23	5.55	32.61	15.85	2.92	0.60	0.09	0.49
Significance	**	**	**	**	**	**	**	**

Source of variation	df								
Genotypes	18	18.55**	35.19**	5305.38**	23.48**	2.281**	0.006**	2.22**	222.5**
Error	36	7.963	6.326	51.54	1.750	0.073	0.0014	0.050	5.021
Total	56								

** = Significant at 1% level of probability. (G1=Kuroda, G2=New Kuroda, G3=Kuroda 35, G4=King Kuroda, G5=Shin Kuroda, 4 G6=Kuroda improved, G7=Shidur, G8=Pusha keshor, G9=Bankim keshor, G10=Orange 5 HYV, G11=Brasilia 2007, G12=BAU Gazor 5, G13=Brasilia Agroflora, G14=Prima Agroflora, 6 G15=Gazor lovely, G16=Autumn King 2, G17= Nantes 5, G18=16'B114-1, G19=21408B).

Table 6. Effect of genotypes on β carotene (mg 100 ml^{-1} of extract), lycopene (mg 100 ml^{-1} of extract), and anthocyanin content (mg 100 g of FW^{-1}) of carrot.

Genotypes	β carotene	Lycopene	Anthocyanin
G1	0.772 ^{e}	0.0310 ^{h}	2.10 ^{p}
G2	0.906 ^{d}	0.0580 ^{b}	41.00 ^{a}
G3	1.011 ^{c}	0.0540 ^{c}	24.56 ^{c}
G4	0.411 ^{k}	0.0180 ^{k}	20.24 ^{e}
G5	1.090 ^{b}	0.0490 ^{d}	17.43 ^{f}
G6	0.739 ^{f}	0.0430 ^{e}	11.64 ^{i}
G7	0.679 ^{g}	0.0290 ^{i}	3.16 ^{n}
G8	0.105 ^{r}	0.0420 ^{f}	16.53 ^{h}
G9	0.133 ^{p}	0.3350 ^{a}	0.89 ^{q}
G10	0.131 ^{q}	0.0090 ^{n}	20.67 ^{d}
G11	0.432 ^{j}	0.0170 ^{l}	37.19 ^{b}
G12	0.585 ^{h}	0.0230 ^{j}	6.95 ^{l}
G13	0.202 ^{m}	0.0170 ^{l}	4.12 ^{m}
G14	0.084 ^{s}	0.0030 ^{o}	16.85 ^{g}
G15	0.158 ^{o}	0.0020 ^{p}	2.72 ^{o}
G16	0.294 ^{l}	0.0120 ^{m}	7.21 ^{k}
G17	0.573 ^{i}	0.0320 ^{g}	0.03 ^{s}
G18	0.161 ^{n}	0.0090 ^{n}	8.25 ^{j}
G19	1.252 ^{a}	0.0490 ^{d}	0.48 ^{r}
$LSD_{0.05}$	0.033	0.002	0.016
$LSD_{0.01}$	0.044	0.003	0.022
Level of significance	**	**	**

Source of variation	df	β carotene	Lycopene	Anthocyanin
Genotypes	18	0.41473**	0.0158400**	437.662**
Error	38	0.00040	0.000002	0.00010
Total	56			

** = Significant at 1% level of probability.(G1=Kuroda, G2=New Kuroda, G3=Kuroda 35, G4=King Kuroda, G5=Shin Kuroda, 4 G6=Kuroda improved, G7=Shidur, G8=Pusha keshor, G9=Bankim keshor, G10=Orange 5 HYV, G11=Brasilia 2007, G12=BAU Gazor 5, G13=Brasilia Agroflora, G14=Prima Agroflora, 6 G15=Gazor lovely, G16=Autumn King 2, G17= Nantes 5, G18=16'B114-1, G19=21408B).

The present study revealed significant genotypic variation among the 19 carrot genotypes for growth, yield, and quality traits, indicating substantial diversity in physiological performance and genetic potential. Because all genotypes were evaluated under the same field conditions, the observed differences can be attributed mainly to inherent genotypic variation in vegetative vigor, assimilate partitioning, storage-root development, and pigment accumulation. Recent studies in carrot have likewise documented broad diversity in shoot-growth traits, root-shape genetics, and phytochemical composition across germplasm and cultivar groups (Bhandari et al., 2022; Loarca et al., 2024; Vega et al., 2024)

Plant height and leaf number are key indicators of vegetative vigor because they influence canopy development, light interception, and the plant's capacity to produce photoassimilates. In the present study, Orange HYV (G10) exhibited the greatest plant height throughout the growth period, whereas 21408B (G19) showed the lowest plant height at the later stages. This suggests that G10 had stronger vegetative growth potential, likely reflecting more vigorous canopy development and better aboveground biomass formation. This interpretation is supported by Loarca et al., (2024), who reported substantial heritable variation in carrot shoot-growth traits, including early vigor and canopy development, across diverse germplasm.

A similar trend was observed for leaf production. Pusha Keshor (G8) produced the highest number of leaves at the early growth stages, while Bankim Keshor (G9) maintained the highest leaf number from 60 DAS onward. In contrast, 21408B (G19) consistently produced fewer leaves. This difference is physiologically important because leaves are the principal source organs supplying carbohydrates to the developing storage root; therefore, genotypes with greater leaf production are expected to support greater assimilate availability for root growth and bulking. The better leaf development in G8 and G9 may partly explain their stronger performance in several yield-contributing traits, whereas the weaker canopy of G19 suggests limited source capacity despite its production of longer roots. Recent carrot research has emphasized that genotype strongly influences shoot-growth traits relevant to crop establishment and biomass production (Loarca et al., 2024).

The results for root traits show that root elongation, radial expansion, and biomass accumulation were not expressed uniformly across genotypes. The clearest example was 21408B (G19), which produced the longest roots but also had the smallest root diameter and the lowest individual root weight. This indicates that root length alone did not ensure higher productivity. Rather, G19 appears to have favored longitudinal growth over radial thickening, resulting in long but slender roots with low biomass. This interpretation is consistent with recent genetic evidence showing that carrot root length- and width-related traits can vary independently and are controlled by distinct loci associated with root shape architecture (Vega et al., 2024).

In contrast, genotypes such as Shidur (G7) and Shin Kuroda (G6) showed greater root diameter, indicating stronger radial expansion and better storage tissue development. The highest individual root weight was recorded in Pusha Keshor (G8), followed by Kuroda 35 (G3) and Orange HYV (G10), suggesting stronger sink strength and more efficient translocation of assimilates to the storage root in these genotypes. A recent comparative root transcriptome study showed that cultivar differences in vascular tissue patterning, xylem differentiation, and secondary cell-wall thickening are associated with storage-root development and root morphology in carrot (Kulkarni et al., 2023).Therefore, the larger diameter and greater root mass observed in some genotypes in the present study may reflect differences in the underlying developmental regulation of radial root growth. Despite this, the highest gross and marketable yield was obtained from King Kuroda (G4), followed by New Kuroda (G2). This indicates that plot-level productivity was determined not by a single component trait but by the combined expression of favorable root size, adequate biomass accumulation, and a low proportion of defective roots. The superiority of G4 is particularly notable because it combined the highest gross and marketable yield with no cracked roots and a relatively low percentage of branched roots. This suggests that G4 achieved a more favorable balance among vegetative growth, assimilate partitioning, root bulking, and structural stability under the present field conditions. The interpretation that productivity depends on coordinated root morphology rather than a single shape parameter is also in line with recent mapping work showing that carrot market-class traits arise from multiple genetically controlled root-shape components (Vega et al., 2024). The variation in cracked and branched roots further emphasizes the agronomic importance of genotype-specific responses. Orange HYV (G10) showed the highest percentage of cracked roots, whereas Kuroda (G1) had the highest proportion of branched roots. Although the present experiment was not designed to isolate the effects of irrigation or nitrogen, recent carrot production research has shown that nitrogen uptake and evapotranspiration vary spatially under field production systems and are closely linked to crop management and root performance (Montazar et al., 2021). Therefore, the lower incidence of cracked and branched roots in genotypes such as King Kuroda (G4) and Shidur (G7) likely reflects greater developmental stability under the prevailing field environment. This point should still be interpreted cautiously, because the present study did not directly measure the mechanisms causing cracking or branching.

Overall, the yield results indicate that carrot productivity was governed by the interaction of source strength, sink development, root morphology, and susceptibility to physiological defects. Genotypes with a balanced expression of these traits, particularly King Kuroda (G4), achieved superior agronomic performance.

The significant variation in β-carotene, lycopene, and anthocyanin contents among genotypes indicates strong genotypic control over pigment biosynthesis. In the present study, 21408B (G19) exhibited the highest β-carotene content despite being inferior in several growth and yield traits. This suggests that nutritional quality and yield performance were not positively associated in all cases, and that some genotypes may allocate proportionally more metabolic resources to carotenoid accumulation than to storage-root biomass production. Bhandari et al. (2022) demonstrated that phytochemical composition in carrot is strongly dependent on genotype, root color, and tissue type, while Coe et al. (2023) showed through population genomics that high-carotenoid orange carrots have distinct genetic signatures related to carotenoid accumulation.

Likewise, Bankim Keshor (G9) showed the highest lycopene content, while New Kuroda (G2) had the highest anthocyanin concentration. These contrasting patterns indicate that the metabolic pathways controlling carotenoid and anthocyanin biosynthesis differ among genotypes. This interpretation agrees with Bhandari et al. (2022), who reported substantial variation in carotenoids, anthocyanins, phenolics, and antioxidant activity among carrot genotypes with different root colors and tissues.

From a breeding and cultivar-selection perspective, these results suggest that selection for high yield and selection for enhanced nutritional quality may require different priorities. King Kuroda (G4) was the best genotype for gross and marketable yield, whereas 21408B (G19) was superior for β-carotene, Bankim Keshor (G9) for lycopene, and New Kuroda (G2) for anthocyanin. Therefore, genotype choice should depend on the production objective, whether the priority is commercial yield, marketability, or nutritional enhancement. Recent genomic and phytochemical studies support this distinction by showing that agronomic improvement and pigment-related quality traits can follow partly different biological and genetic trajectories in carrot (Bhandari et al., 2022; Coe et al., 2023).

4. Conclusion

The present study demonstrated substantial genotypic variation among the 19 carrot genotypes for growth, yield, marketability, and nutritional quality. Based on overall agronomic performance, King Kuroda (G4) was identified as the most promising genotype, as it produced the highest gross yield and marketable yield, with no cracked roots and a low percentage of branched roots. These characteristics indicate its strong potential for commercial cultivation and adaptation under the experimental conditions. In contrast, 16´B114-1 (G18) showed the poorest performance, recording the lowest gross and marketable yield. The results also revealed that some genotypes were superior for specific quality traits. 21408B (G19) showed the highest β-carotene content, Bankim Keshor (G9) had the highest lycopene content, and New Kuroda (G2) recorded the highest anthocyanin content. Therefore, although King Kuroda was the best genotype in terms of yield and marketability, genotypes such as 21408B, Bankim Keshor, and New Kuroda may be considered promising genetic resources for nutritional quality improvement and future breeding programs. Considering the results of the present one-year study, King Kuroda (G4) may be recommended as the most promising genotype for yield and marketability, while 21408B (G19), Bankim Keshor (G9), and New Kuroda (G2) may be regarded as promising for quality-related traits. However, before any final recommendation or potential release as superior local varieties, these genotypes should be evaluated further through multi-year and multi-location trials to confirm their performance, stability, and adaptability under diverse agroecological conditions.

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