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RESEARCH ARTICLE

Multivariate analysis of morphological diversity in six orange carrot germplasms cultivated in semi-arid regions of Algeria

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Abstract

This study explores the morphological differentiation among six orange carrot germplasms, Muscad d'Alger, Touchon, Breclium, Nantaise, Super Muscad and Nantaise améliorée, cultivated under semi-arid conditions in Algeria. A total of 30 morphological descriptors, based on criteria from both the International Union for the Protection of New Varieties of Plants (UPOV) and the International Plant Genetic Resources Institute (IPGRI), were utilised to evaluate phenotypic variability and identify the most informative traits for diversity assessment, to leverage them in selection and improvement programs. The descriptors encompassed structural features of the plant, leaf morphology and root characteristics. To quantify diversity and identify classification patterns, Shannon–Weaver diversity index (H'), Principal Component Analysis (PCA) and hierarchical clustering were applied. The H' values varied widely, from 0 (e.g., root branching) to 1.32 for traits such as the length-to-width ratio of the root, shape of the root in longitudinal section, diameter of the core relative to total diameter, extent of green pigmentation in longitudinal section, root emergence above soil level and timing of root tip colouration. The average H' across all descriptors and populations was 1.32, indicating a high level of morphological diversity. PCA results revealed that 11 out of the 30 traits contributed most significantly to the observed variance, underscoring their potential utility in discriminating between genotypes. Further multivariate analyses, including factorial correspondence and cluster analyses, which incorporated four qualitative, four pseudo-qualitative and twenty-two quantitative traits, enabled the grouping of the studied varieties into three distinct clusters. The first cluster contained Muscad varieties, the second included Touchon and Breclium, while the third comprised Nantaise and its improved variant. These findings provide a valuable framework for the strategic selection, conservation and utilisation of orange carrot germplasms in breeding programs adapted to semi-arid environments.

Keywords: diversity index; morphological descriptors; multivariate analysis; orange carrot

Introduction

The carrot (*Daucus carota* L.) is a biennial dicotyledonous plant, exhibiting a monoecious and protandrous reproductive system and is taxonomically classified within the Apiaceae (Umbelliferae) family as a root vegetable. It is recognised as one of the earliest domesticated crops in Central Asia, with archaeological evidence suggesting its cultivation predates 5000 BCE (1,2). Globally, carrots hold considerable agricultural, nutritional and scientific importance due to their roots' exceptional biochemical composition. These roots represent a principal dietary source of α- and β-carotene (precursors to vitamin A), along with notable amounts of riboflavin, thiamine, niacin, vitamin C, dietary fibre, carbohydrates, minerals, proteins, essential oils and lipids. Moreover, carrots contain a rich profile of antioxidants, particularly carotenoids such as alpha-carotene, beta-carotene, lycopene and lutein, which contribute to the characteristic orange, red and yellow pigmentation of different cultivars (3,4).

The nutritional and antioxidant properties of carrots have been associated with several health benefits, including cholesterol regulation, visual health enhancement and a potential reduction in cancer risk (5). In particular, the high concentration of provitamin A compounds makes carrots instrumental in combating vitamin A deficiency-related disorders, such as night blindness, which remains a significant public health concern in many developing nations. Given these multifaceted benefits, global carrot consumption has seen a steady rise over recent decades (6). Carrot cultivation demonstrates high adaptability to diverse environmental conditions. The crop performs optimally in well-drained soils with a pH range of 6.5 to 7.0 and it tolerates high relative humidity levels (90–99 %) (7). It can grow within a temperature range of 7 °C to 24 °C, although deviations from this range can adversely affect both development and quality (8). As a

glycophytic root crop, carrot is notably sensitive to salinity stress, which can impair growth and productivity (2).

From a genetic perspective, carrots possess extensive intraspecific diversity and genomic plasticity, which have facilitated their successful cultivation across a wide range of agroecological zones. While Europe remains the leading region in per-hectare yield, Asia has witnessed a substantial expansion in carrot cultivation over the past five decades, particularly in warmer climates. This genetic variability provides a robust foundation for breeding programs targeting traits such as drought or heat tolerance, resistance to biotic stresses (e.g., *Alternaria* leaf blight), weed competitiveness, adaptability to different soil chemistries, modulation of flowering time and enhanced seed yield (9). These attributes are critical for improving the resilience and productivity of carrot cultivars under climate variability and evolving agricultural challenges. Following the release of the carrot reference genome, interest in carrot cultivation has significantly increased, paralleled by a surge in scientific investigations focused on this crop (1). This heightened attention suggests the potential for a further global expansion of carrot production. To date, over a thousand studies have examined the effects of climate variability on carrot cultivation, with particular focus on genetic attributes, developmental stages, physiological behaviour, yield capacity and the nutritional composition of roots. Major research contributions have come from regions including Afghanistan, Iran, broader Asia, North Africa, Europe, Eastern Central Asia and China (9). In South America, significant input has been provided by Argentina and Brazil (9,10).

Global production, predominantly centred on orange-fleshed varieties, has quadrupled in the last 45 yr, reaching over 34.17 t/ha. This growth has positioned carrots among the top ten most economically significant vegetable crops worldwide (6,11). Leading producers, namely the USA, China, Uzbekistan and Poland, account for approximately 60 % of total global output (6). Within Africa, Morocco ranks as the largest carrot producer, cultivating 14749 ha with an average yield of 32.38 t/ha. Other African nations with expanding carrot cultivation include Algeria, Niger, Cameroon, Senegal and several others (2,12). Several investigations have been carried out across various agro-ecological zones in Algeria to enhance knowledge on the chemical composition and antioxidant potential of locally cultivated carrots (13,14). Moreover, some authors have explored the impact of salinity stress (NaCl) on root development and performance of *Daucus carota* subsp. *sativus* under Algerian growing conditions (2).

The cultivated carrot, *D. carota* subsp. *sativus* represents one of twelve recognised subspecies within the species. Significant morphological variability has been reported, largely attributed to frequent hybridisation events within the *D. carota* complex. The genetic differentiation between wild and domesticated carrots can be evaluated through both isozyme profiling and morphological trait analysis (15). Accurate identification and characterisation of genetically diverse germplasm is essential for targeted breeding strategies and effective genetic improvement of the crop (16).

Integrating biochemical (protein level) markers with morphological characterisation enhances the accuracy and reliability of germplasm evaluation (17,18). Phenotypic characterisation remains a practical and widely used approach for assessing genetic diversity and guiding the effective use of plant genetic resources (16,19,20). Despite previous research efforts, the morphological and genetic diversity of orange carrot populations in Algeria remains insufficiently documented. This research gap has motivated the present study, which focuses on analysing the morphological and phenological variability within *D. carota* varieties in order to identify distinctive traits that may facilitate the classification and utilisation of this genetic diversity.

The present study aims to evaluate the morphological variability among six orange carrot germplasms cultivated in semi-arid regions of Algeria, which may hold significant agro-ecological and nutritional value. A total of 30 morphological traits, encompassing characteristics of the plant, foliage and root structures, were recorded following the descriptors established by the UPOV and IPGRI (21,22). Phenotypic differentiation among accessions was assessed to identify the most influential traits contributing to morphological diversity. For genotype classification, multivariate statistical tools including PCA, hierarchical cluster analysis and the Shannon-Weaver diversity index (H') were employed.

Materials and Methods

Plant material

This study focused on assessing morphological variation among six orange carrot (*Daucus carota* subsp. *sativus*) germplasms: Muscad d'Alger, Super Muscad, Touchon, Nantaise, Nantaise améliorée and Breclium (Fig. 1). These germplasms are commonly cultivated, marketed and consumed across Algeria, where the prevailing arid to semi-arid climate provides favourable conditions for their growth and adaptability. The plant material used in the experiment was sourced from the local market. The trial was conducted using a Completely Randomised Design (CRD) with a single factor. Sowing was carried out in sandy clay soil, with rows spaced 100 cm apart. Three weeks after sowing, seedlings were thinned to maintain a final spacing of one plant every 5 cm, ensuring adequate plant development and ease of management. Each experimental unit consisted of one row representing a single germplasm. Uniform

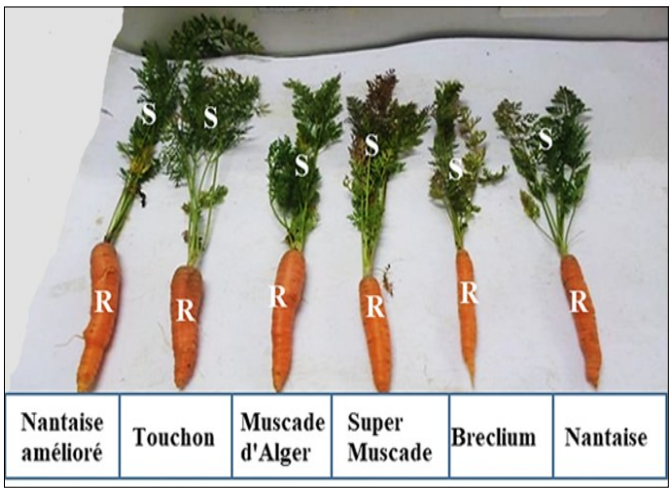

Fig. 1. Morphological variation and sampled organs of *D. carota* subsp. *sativus* used for trait analysis.

S: Leaf samples; R: Root samples

agronomic practices, including irrigation and manual weeding, were applied across all plots throughout the growing period. Six distinct varieties were identified corresponding to the six selected germplasms following sowing, as depicted in Fig. 1.

After 160 days of growth, all identified orange carrot germplasms were evaluated using a set of 30 morphological traits, both quantitative and qualitative, related to the plant, leaves, foliage and roots (Fig. 1). Within each replication, five centrally located plants per accession were selected for data collection to ensure representative sampling. The selection of traits was guided by the descriptor lists provided by the UPOV and the IPGRI (Table 1).

Morphological descriptors and data collection

A total of thirty morphological traits were recorded, combining both quantitative and qualitative characteristics, based on the standardised descriptor lists provided by UPOV (2015) and IPGRI (1998). These traits encompassed 4 qualitative, 4 pseudo-qualitative and 22 quantitative parameters. The assessment involved various parts of the plant, including foliage, leaves, roots and overall plant structure. Foliage evaluation focused on crown width, while leaf traits included orientation, total length (including petiole), degree of segmentation, green colour intensity and the presence of anthocyanin pigmentation in the petiole. Root-related descriptors comprised measurements of length and width, pigmentation of the shoulder area, shape in longitudinal section, shoulder and tip shape, external colour, degree of surface ridging, the ratio of core to total diameter, intensity and distribution of core colour, comparison of core and cortex colouration, internal green pigmentation and root protrusion above the soil. Additional root traits included timing of tip development and tip colouration in longitudinal section, especially in blunt-tipped varieties, as well as RB and total weight. At the whole-plant level, traits such as bolting tendency and the height of the primary umbel at flowering were also recorded (Table 1).

These traits encompassed descriptors associated with different structural components of the plant, including the whole plant, foliage and root system and were used to construct a numerical data matrix (Table 1). Morphological variation was assessed using five representative individuals per accession, based on the 30 selected descriptors. To ensure data reliability and minimise observational bias, all measurements were performed consistently by the same two researchers throughout the study.

Data analysis

Data analysis was conducted to evaluate both intra- and inter-germplasm morphological diversity based on traits related to the plant, leaf and root structures (Table 1). Morphological and phenological data were subjected to multivariate statistical analyses and clustering techniques using XLSTAT- Premium v2016.02 software. PCA was employed to classify the varieties within germplasms and to identify the main axes and morphological descriptors contributing most to overall variation. A similarity matrix was used to compute eigenvalues and germplasm scores and the first two principal components, accounting for the greatest proportion of variance, were selected to generate two-dimensional scatter plots for visualising the relationships among varieties. Hierarchical Cluster Analysis was performed using Williams' minimum variance method (23), with squared Euclidean distance as the dissimilarity measure, following the approach established previously (24).

Each traits' variability was measured using the Shannon-Weaver diversity index (H') (25,26). This index was calculated using the formula:

$$H' = -\sum pi \, (\log_2 pi) / \log_2 n \qquad \text{(Eqn. 1)}$$

Where pi denotes the proportion of each phenotypic state of a descriptor and n represents the total number of states observed for that trait. Frequency distributions for all morphological traits were generated using Microsoft Excel 2013. The Shannon-Weaver index ranges from 0 to 1, where a value of 0 indicates no diversity and a value of 1 denotes maximum diversity across the sampled population (Table 1).

Results and Discussion

Assessment of morphological variation using the Shannon-Weaver diversity index

As presented in Table 1, the Shannon-Weaver diversity index values for the evaluated morphological descriptors, both quantitative and qualitative, ranged from 0 to 1.32. The lowest index value (0) was observed for Root Branching (RB), indicating no variability among accessions for this trait. In contrast, the highest diversity value (1.32) was recorded for several traits, including Root Length-to-Width Ratio (RL/RW), Root Shape in Longitudinal Section (RSLS), Root Diameter of Core Relative to Total Diameter (RDCRTD), Root Extent of Green Colouration of the Interior (REGCI), Root Protrusion Above Soil surface (RPAS) and Root Tip Colouration Time in Longitudinal Section (RTCTLS). The average Shannon-Weaver index across all descriptors was 1.32, reflecting a relatively high level of morphological diversity within the assessed germplasms.

The lowest phenotypic variation was observed in RB, which recorded a diversity index of 0, indicating uniformity across all germplasms for this trait. In contrast, high levels of morphological variability were identified in several traits, with the highest Shannon–Weaver index values (1.32) recorded for RL/RW, RSLS, RDCRTD, REGCI, RPAS and RTCTLS. These were followed by relatively high diversity in Root Ridging of Surface (RRS) (1.11), Leaf Attitude (LA) (1.01), Root Weight (RWt) (1), Root Intensity of External Colour (RIEC) (1), Root Shape of Shoulder (RSS) (1) and Root Tip (when fully developed) (RT) (1).

Moderate variability was observed for traits such as Root Colour of Core (RCC) (0.85), Root Cortex Colour (RCCt) (0.85), Root Extent of Green Colour of Skin of Shoulder (REGCSS) (0.85), Root External Colour (REC) (0.85) and Leaf Intensity of Green Colour (LGCI) (0.85). Remaining traits exhibited moderate variation (H' = 0.44–0.69). These included Foliage Width of Crown (FoWC) (0.69), Leaf Length Including Petiole (LLIP) (0.69), Root Anthocyanin Colouration of Skin of Shoulder (RACSS) (0.69), Root Length (RL) (0.69) and Plant Tendency to Bolting (PTB) (0.69). For varieties with blunt tip, Root Time of Development of Rounded Tip (RTDRT) recorded 0.66, followed by Leaf Division (LD) (0.64), Root Intensity of Colour of Core (RICC) (0.64), Root Colour of Core Compared to Colour of Cortex (RCCCC) (0.64) and Plant Height of the Primary Umbel at the Time of Flowering (PHPUTF) (0.64). Lower variability was noted for Root Width (RW) (0.54) and Leaf Anthocyanin Colouration of Petiole

Table 1. Morphological descriptors used to characterise the morphology of six distinct germplasms of orange carrot cultivated in Algeria

Sources	Descriptor	Descriptor acronym	Type	State and class	Muscad d'Alger	Super Muscad	Touchon	Nantaise améliorée	Nantaise Breclium		Frequency (%)	Diversity index (H')
UPOV	Foliage: width of crown	FOWC	QN	Narrow : 3 Medium : 5 Broad :7	5	3	5	3	3	5	50 % 50 %	0.69
UPOV	Leaf: attitude	LA	QN	Erect:1 semi-erect: 3 prostrate:5	3	3	3	5	5	1	16.6 % 50 % 33.33 %	1.01
UPOV	Leaf: length (including petiole)	LLIP	QN	very short:1 short:3 medium:5 ong:7 very long:9	3	5	5	3	3	5	50 % 50 %	0.69
UPOV	Leaf: division	LD	QN	Fine:3 Medium:5 Coarse:7	5	5	5	3	3	5	33.33 % 66.66 %	0.64
UPOV	Leaf: intensity of green colour	LGCI	QN	Light:3 Medium:5 Dark:7	5	5	5	3	5	7	16.6 % 66.66 % 16.6 %	0.85
UPOV	Leaf: anthocyanin colouration of the petiole	LPAC	QL	Absent:1 Present:9	1	9	9	9	9	9	16.66 % 83.33 %	0.44
UPOV	Root: length	RL	QN	very short:1 short:3 medium:5 long:7 very long: 9	5	7	5	7	7	5	50 % 50 %	0.69
UPOV	Root: width	RW	QN	Narrow:3 Medium:5 Broad: 7	5	5	7	7	5	5	66.66 % 33.33 %	0.54
UPOV	Root: ratio length/ width	RL/RW	QN	very small:1 small:3 medium:5 large:7 very large: 9	5	7	3	9	7	5	16.6 % 33.33 % 33.33 % 16.6 %	1.32
UPOV	Root: shape in longitudinal section	RSLS	PQ	Circular: 1 Obovate: 2 Medium obtriangular: 3 Narrow obtriangular: 4 Narrow obtriangular to narrow oblong: 5 Narrow oblong: 6	6	5	3	4	5	3	33.33 % 16.6 % 33.33 % 16.6 %	1.32
UPOV	Root: shape of the shoulder	RSS	PQ	Flat:1 flat to rounded: 2 rounded: 3 rounded to conical: 4 conical:5	1	3	3	5	3	5	16.6 % 50 % 33.33 %	1
UPOV	Root: tip (when fully developed)	RT	QN	Blunt: 1 slightly pointed: 2 strongly :pointed: 3	2	1	1	3	2	1	50 % 33.33 % 16.6 %	1
UPOV	Root: external colour	REC	PQ	white: 1 yellow: 2 orange: 3 pinkish red: 4 red: 5 purple: 6	3	3	5	3	3	4	66.66 % 16/6 % 16/6 %	0.85
UPOV	Root: intensity of external colour	RIEC	QN	Light: 3 Medium: 5 Dark: 7	3	7	5	5	5	7	16.6 % 50 % 33.33 %	1
UPOV	Root: anthocyanin colouration of the skin of the shoulder	RACSS	QL	Absent: 1 Present: 9	1	1	9	1	9	9	50 % 50 %	0.69
UPOV	Root: extent of green colour of the skin of the shoulder	REGCSS	QN	Absent or very small: 1 Small:3 Medium:5 Large: 7 Very large: 9	1	3	3	5	3	3	16.6 % 66.66 % 16/6 %	0.85

UPOV	Root: ridging of the surface	RRS	QN	Absent or very weak: 1 Weak: 3 Medium:5 Strong: 7	5	3	1	3	1	5	33.33 % 33.33 % 33.33 %	1.11
UPOV	Root: diameter of core relative to total diameter	RDCRTD	PQ	very strong: 9 very small: 1 small: 3 medium:5 large:7 very large:9	5	5	3	7	9	3	33.33 % 33.33 % 16.6 % 16.6 %	1.32
UPOV	Root: colour of cortex	RCCt	QL	White:1 Yellow:2 Orange:3 Pinkish red:4 Red:5 Purple: 6	2	2	5	2	2	3	66.66 % 16.6 % 16.6 %	0.85
UPOV	Root: intensity of colour of the core	RICC	QN	Light:3 Medium:5 Dark: 7	3	3	5	5	5	5	33.33 % 66.66 %	0.64
UPOV	Root: colour of core compared to colour of cortex	RCCCC	QN	Lighter:1 Same:2 Darker: 3	3	3	2	3	3	2	33.33 % 66.66 %	0.64
UPOV	Root: extent of green colouration of the interior (in longitudinal section)	REGCI	QN	absent or very small: 1 small: 3 medium:5 large:7 very large:9	5	7	3	3	7	1	16.6 % 33.33 % 16.6 % 33.33 %	1.32
UPOV	Root: protrusion above the soil	RPAS	QN	absent or very small: 1 small: 3 medium: 5 large: 7 very large: 9	7	7	5	1	3	1	33.33 % 16.6 % 16.6 % 33.33 %	1.32
UPOV	Varieties with blunt tip only: Root: time of development of the rounded tip	RTDRT	QN	Early: 3 Medium:5 Late: 7	/	3	5	/	/	5	16.6 % 33.33 %	0.66
UPOV	Root: time of colouration of the tip in longitudinal section	RTCTLS	QN	very early:1 early:3 medium: 5 late: 7 very late: 9	5	7	1	5	3	3	16.6 % 33.33 % 33.33 % 16.6 %	1.32
UPOV	Root: colour of core	RCC	PQ	White:1 Yellow:2 Orange: 3 pinkish red:4 red: 5 purple: 6	2	2	5	2	2	3	66.66 % 16.6 % 16.6 %	0.85
IPGRI	Root branching	RB	QN	Absent: 0 Few: 3 Average: 5 Dense: 7	0	0	0	0	0	0	0 %	/
IPGRI	Root: weight	RWt	QN	Light (≤0.09): 1 Intermediate(0.09-0.40): 2 Heavy (≥0.40): 3	1	2	1	2	3	1	50 % 33.33 % 16.6 %	1
UPOV	Plant: tendency to bolt	PTB	QN	Weak:3 Medium: 5 Strong: 7	5	5	3	5	3	3	50 % 50 %	0.69
UPOV	Plant: height of the primary umbel at the time of its flowering	PHPUTF	QN	Short:3 Medium:5 Tall: 7	5	5	3	3	3	3	66.66 % 33.33 %	0.64

(LPAC) (0.44). A low index value indicated the dominance of a single trait state among accessions, while a higher value reflected a more even distribution across character states, as demonstrated by the frequency distributions.

Principal Component Analysis (PCA)

PCA revealed substantial morphological differentiation among the six orange carrot (*Daucus carota* subsp. *sativus*) germplasms under study. The first two principal components collectively accounted for 69.52 % of the total phenotypic variation, with PC1 and PC2 explaining 42.31 % and 27.20 %, respectively (Fig. 2). Out of the 30 evaluated morphological descriptors, eleven

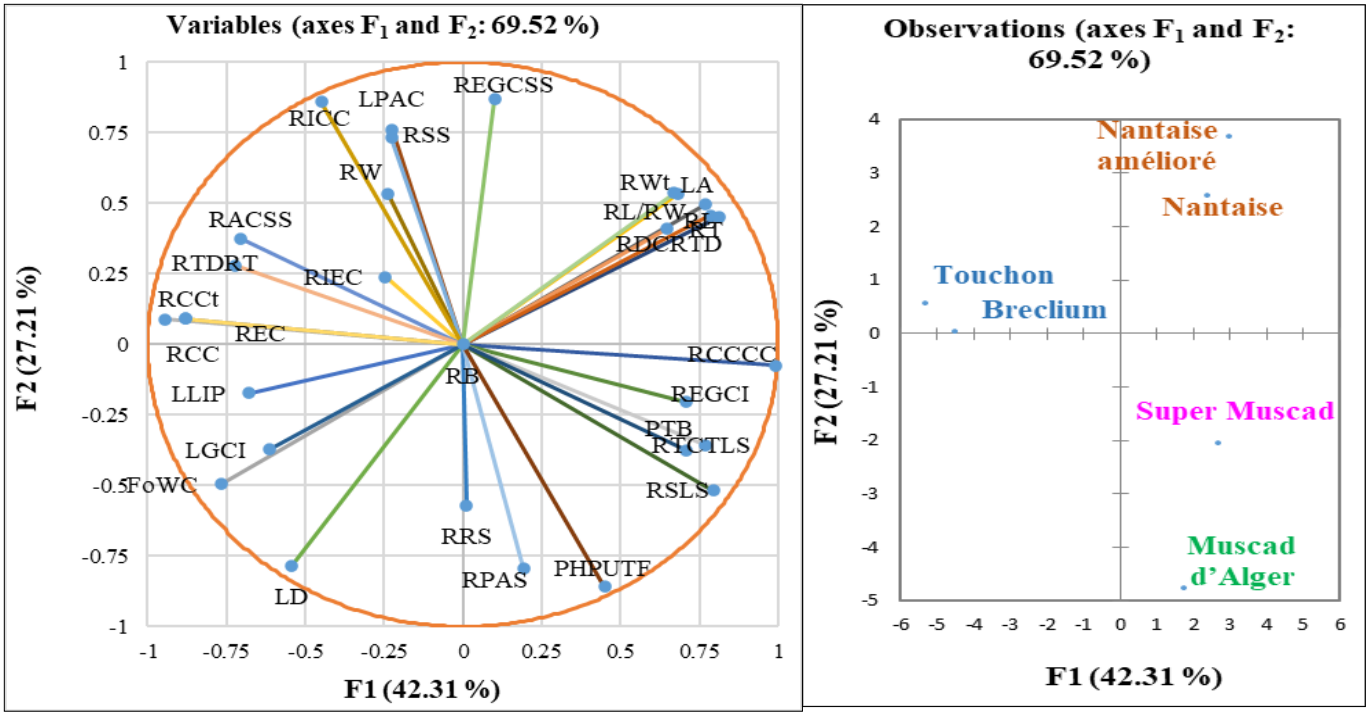

Fig. 2. Principal component analysis illustrating.

A. Contribution of UPOV and IPGRI descriptors to the observed morphological variability, B. Differentiation among the studied orange carrot germplasms

FoWC: Foliage: width of crown; LA: Leaf: attitude; LLIP: Leaf: length (including petiole); LD: Leaf: division; LGCI: Leaf: intensity of green colour; LPAC: Leaf: anthocyanin colouration of petiole; RL: Root: length; RW: Root: width; RL/RW: Root: ratio length/ width; RSLS: Root: shape in longitudinal section; RSS: Root: shape of shoulder; RT: Root: tip (when fully developed); REC: Root: external colour; RIEC: Root: intensity of external colour; RACSS: Root: anthocyanin colouration of skin of shoulder; REGCSS: Root: extent of green colour of skin of shoulder; RRS: Root: ridging of surface; RDCRTD: Root: diameter of core relative to total diameter; RCCt: Root: colour of cortex; RICC: Root: intensity of colour of core; RCCCC: Root: colour of core compared to colour of cortex; REGCI: Root: extent of green colouration of interior (in longitudinal section); RPAS: Root: protrusion above soil; RTDRT: Root: time of development of rounded tip (varieties with blunt tip only); RTCTLS: Root: time of colouration of tip in longitudinal section; RCC: Root: colour of core; RB: Root branching; RWt: Root: weight; PTB: Plant: tendency to bolting; PHPUTF: Plant: height of primary umbel at time of its flowering

were identified as the most informative for distinguishing among the germplasms. The relative contributions of all descriptors to the first two principal axes are depicted in Fig. 2. Key descriptors contributing predominantly to PC1 included LA, RL, RL/RW, RSLS, RT, RDCRTD, RCCCC, REGCI and RWt. These variables were thus determined to be critical for explaining the observed morphological diversity. In contrast, the second principal component (PC2) was primarily associated with LPAC, RW, RSS, REGCSS and RICC (Fig. 2). The distribution of the six orange carrot germplasms along the two principal component axes enabled a clear separation into four distinct morphological groups (Fig. 3). Group (a) was exclusively composed of Super Muscad variety. Group (b) encompassed the Touchon and Breclium varieties, both located on the negative side of the biplot. Group (c) included Nantaise améliorée and Nantaise, while group (d) was represented solely by the Muscad d'Alger variety.

Correlation analysis among morphological traits

To explore the interrelationships among the quantitative and qualitative morphological variables, Pearson correlation coefficients (r) were calculated. Out of all measured traits, eleven demonstrated statistically significant correlations at the $p < 0.05$ level. Notably, REC was strongly and positively correlated with RCCt and RCC (r= 0.987 for both). Other significant positive correlations included those between RL and RWt, as well as the RL/RW (r= 0.894), RSLS and RCCCC (r= 0.853), RSS and REGCSS (r= 0.840) and RDCRTD and RWt (r= 0.908). Positive associations were also found between RPAS and PHPUTF (r= 0.843), as well as between RTCTLS and PTB (r= 0.870). Additionally, perfect correlations were observed between FoWC and RL (r= 1) and between RCCt and RCC (r= 1).

Cluster analysis

A hierarchical cluster analysis incorporating both qualitative and quantitative morphological descriptors was performed to examine the overall diversity structure and interrelationships among the six orange carrot germplasms. The resulting dendrogram revealed three principal clusters. Cluster I (C1) comprised the Super Muscad and Muscad d'Alger accessions (Fig. 4). Within this group, Muscad d'Alger was characterised by several distinctive features, including a medium RL, a moderate RL/RW, a narrow oblong RSLS, a slightly pointed RT, a medium REGCI and a relatively low root weight (RWt ≤ 0.09). The Super Muscad accession exhibited the closest morphological similarity to Muscad d'Alger within this cluster.

The second cluster (C2) grouped the Breclium and Touchon accessions. Touchon was characterised by a medium LGCI, red REC, a moderate RIEC and red pigmentation in both the root cortex (RCCt) and core (RCC). In contrast, Breclium displayed a darker LGCI, a pinkish-red REC, a more intense RIEC and a distinctive orange colouration in both the root cortex

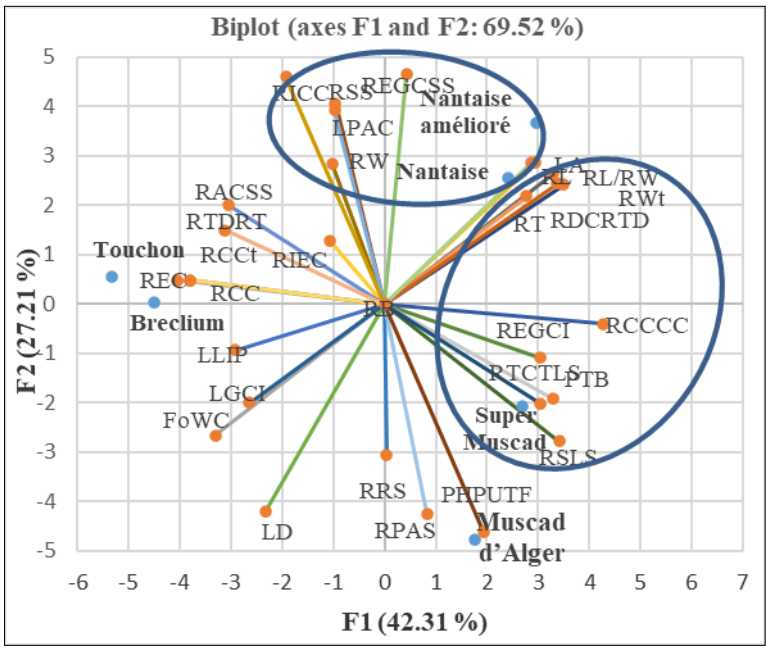

Fig. 3. Biplot representation of orange carrot germplasm inter-accessions, positioned according to the first two principal component axes.

FoWC: Foliage: width of crown; LA: Leaf: attitude; LLIP: Leaf: length (including petiole); LD: Leaf: division; LGCI: Leaf: intensity of green colour; LPAC: Leaf: anthocyanin colouration of petiole; RL: Root: length; RW: Root: width; RL/RW: Root: ratio length/ width; RSLS: Root: shape in longitudinal section; RSS: Root: shape of shoulder; RT: Root: tip (when fully developed); REC: Root: external colour; RIEC: Root: intensity of external colour; RACSS: Root: anthocyanin colouration of skin of shoulder; REGCSS: Root: extent of green colour of skin of shoulder; RRS: Root: ridging of surface; RDCRTD: Root: diameter of core relative to total diameter; RCCt: Root: colour of cortex; RICC: Root: intensity of colour of core; RCCCC: Root: colour of core compared to colour of cortex; REGCI: Root: extent of green colouration of interior (in longitudinal section); RPAS: Root: protrusion above soil; RTDRT: Root: time of development of rounded tip (varieties with blunt tip only); RTCTLS: Root: time of colouration of tip in longitudinal section; RCC: Root: colour of core; RB: Root branching; RWt: Root: weight; PTB: Plant: tendency to bolting; PHPUTF: Plant: height of primary umbel at time of its flowering

(RCCt) and core (RCC). The third cluster (C3) included the Nantaise germplasm, represented by two accessions: Nantaise and Nantaise améliorée. Nantaise améliorée was notably characterised by broader RW and a moderate REGCSS. In contrast, Nantaise exhibited medium RW and a more limited green REGCSS.

This study represents the first systematic investigation of morphological diversity among orange carrot (*Daucus carota* subsp. *sativus*) germplasms cultivated in Algeria. It employs internationally recognised descriptors established by UPOV (2015) and IPGRI (1998) (21,22). The analysis of plant, leaf and root traits across accessions from the Ms'ila region revealed a notable level of phenotypic variation, as reflected by an average Shannon-Weaver diversity index of 1.32. This diversity underscores the significance of Algerian agro-ecological conditions in shaping local adaptation and phenotypic differentiation within orange carrot populations, reinforcing the countrys' role as an important reservoir of carrot genetic diversity within the Mediterranean context. Through the implementation of multivariate approaches, namely factorial correspondence analysis and hierarchical clustering, the studied accessions were effectively categorised into three

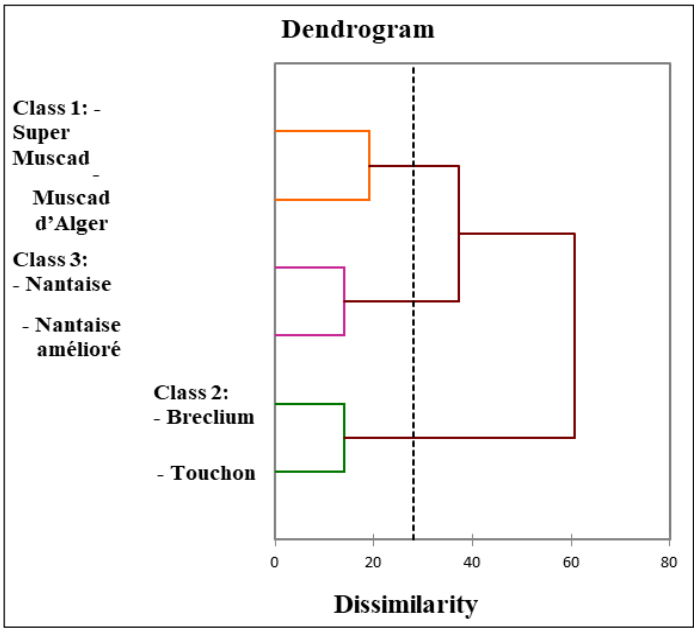

Fig. 4. Dendrogram showing morphological relationships among six orange carrot germplasms in Algeria based on 30 descriptors.

morphologically distinct groups. This structured classification not only highlights the extent of intra-specific variation but also provides a robust framework for future germplasm conservation and breeding strategies tailored to semi-arid environments.

The analysis indicated that a restricted subset of descriptors demonstrated substantial discriminative power among the studied accessions. Notably, nine quantitative traits, LA, RL, RL/RW, RT, PTB, RWt, RTCTLS, REGCI and RCCCC, alongside two pseudo-qualitative traits, RSLS and RDCRTD, were identified as the principal morphological variables driving differentiation among the six orange carrot germplasms (Fig. 3, Table 1).

These traits correspond with the core morphological description criteria outlined by UPOV and IPGRI for carrot (*D. carota* L.) germplasm evaluation. The classification outcomes were in agreement with previously established frameworks for morphological differentiation of carrot accessions, as documented in studies conducted in other regions (27–30). In this context, the first cluster included two Muscad varieties (Muscad d'Alger and Super Muscad), distinguished by a moderate RDCRTD, low RICC, pronounced RPAS and intermediate PHPUTF.

The second cluster comprised the Touchon and Breclium accessions, which were characterised by medium-sized roots with blunt tips, a defined RTDRT, identical RCCCC, reduced RDCRTD and a medium obtriangular RSLS. The third cluster corresponded to the Nantaise germplasm, encompassing two accessions (Nantaise améliorée and Nantaise), both distinguished by finely divided leaves (LD) and a prostrate LA.

Observed phenotypic differentiation among the germplasms can be attributed to both genetic diversity and environmental influences (16,19). The substantial intraspecific variation in carrot (*D. carot*a L.) with respect to traits such as total plant weight, root weight, root shape, dimensions and pigmentation was noticed (28,30,31). The substantial intrinsic variability observed in orange carrot germplasms underscores their potential as a resilient crop in the face of climate change, while also contributing to global food security strategies. Discrepancies in reported outcomes across different studies are often attributable to variations in the genetic materials employed and the specific environmental conditions under which the experiments were conducted. The application of comprehensive morphological descriptors, encompassing traits related to the plant, leaves and roots, demonstrated a high degree of phenotypic diversity, facilitating effective differentiation among the evaluated germplasms. Comparable levels of resolution have previously been achieved through molecular marker analyses in carrot studies (32,33).

Multivariate analyses based on morphological traits continue to provide valuable insights, facilitating the selection and improvement of species adapted to specific geographical regions (16). Such techniques have been widely applied in carrots for morphological and agronomic description (28,30,31). In the current study, multivariate analyses demonstrated that root-related descriptors accounted for the highest proportion of morphological variation (Fig. 1 & 2, Table 1). These traits have consistently been recognised as critical parameters for the characterisation of carrot accessions in prior research (28,30,31).

Conclusion

This study highlights the significance of plant, leaf and root morphological traits in evaluating the genetic diversity of orange carrot (*D. carota* subsp. *sativus*) germplasms cultivated in Algeria. The results provide a valuable foundation for selection strategies and support the effective conservation and utilisation of carrot genetic resources in breeding programs. The morphological dataset, comprising 4 qualitative, 4 pseudo-qualitative and 22 quantitative descriptors, proved effective for distinguishing accessions within this taxonomically complex species. To further enhance the diversity inventory, future efforts should focus on expanding germplasm collection and characterisation across broader agro-ecological zones. Additionally, integrating morphological analyses with molecular tools will enable a more robust validation of diversity patterns and promote sustainable management of Algerias' orange carrot genetic resources.

Authors' contributions

HKB contributed to data collection and analysis and drafted and finalized the manuscript. BR critically reviewed, corrected, and edited the final manuscript. LB contributed to data collection and edited the draft and final versions of the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Iorizzo M, Senalik DA, Ellison SL, Grzebelus D, Cavagnaro PF, Allender C, et al. Genetic structure and domestication of carrot (*Daucus carota* subsp. *sativus*) (Apiaceae). Am J Bot. 2013;100(5):930-8. https://doi.org/10.3732/ajb.1300055
2. Lallouche B, Hadj Kouider B. Evaluate the salt tolerance of Algerian carrot (*Daucus carota* L.) germplasm using germination, biochemical parameters and plant growth potential. Afr J Biol Sci. 2025;7(4):734-51.
3. Boadi NO, Badu M, Kortei NK, Saah SA, Annor B, Mensah MB, et al. Nutritional composition and antioxidant properties of three varieties of carrot (*Daucus carota*). Sci Afr. 2021;12:e00801. https://doi.org/10.1016/j.sciaf.2021.e00801
4. Purewal SS, Verma P, Kaur P, Sandhu KS, Singh RS, Kaur A, et al. A comparative study on proximate composition, mineral profile, bioactive compounds and antioxidant properties in diverse carrot (*Daucus carota* L.) flour. Biocatal Agric Biotechnol. 2023;48:102640. https://doi.org/10.1016/j.bcab.2023.102640
5. Sharma KD, Karki S, Thakur NS, Attri S. Chemical composition, functional properties and processing of carrot - a review. J Food Sci Technol. 2012;49(1):22-32. https://doi.org/10.1007/s13197-011-0310-7
6. Food and Agriculture Organization of the United Nations. World food and agriculture - statistical yearbook 2020. Rome; 2020.
7. Levizou E, Papadimitriou T, Papavasileiou E, Papadimitriou N,

Kormas KA. Root vegetables bioaccumulate microcystins-LR in a developmental stage-dependent manner under realistic exposure scenario: the case of carrot and radish. Agric Water Manag. 2020;240:106274. https://doi.org/10.1016/j.agwat.2020.106274

8. Maynard DN, Hochmuth GJ. Handbook for vegetable growers. New York: John Wiley & Sons; 1997

9. Bolton A, Klimek-Chodacka M, Martin-Millar E, Grzebelus D, Simon PW. Genome-assisted improvement strategies for climate-resilient carrots. In: Genomic designing of climate-smart vegetable crops. Cham: Springer International Publishing; 2020. p. 309-43 https://doi.org/10.1007/978-3-319-97415-6_6

10. Cerezal-Mezquita P, Bugueño-Muñoz W. Drying of carrot strips in indirect solar dehydrator with photovoltaic cell and thermal energy storage. Sustainability. 2022;14(4):2147. https://doi.org/10.3390/su14042147

11. Bolton A, Simon P. Variation for salinity tolerance during seed germination in diverse carrot [*Daucus carota* (L.)] germplasm. HortScience. 2019;54(1):38-44. https://doi.org/10.21273/HORTSCI13333-18

12. Djoufack MMT, Kouam EB, Foko EMK, Anoumaa M, Meli GRL, Kaktcham PM, et al. Determinants and constraints of carrot (*Daucus carota* L.) production and marketing in Cameroon. PLoS One. 2024;19 (1):e0296418. https://doi.org/10.1371/journal.pone.0296418

13. Ksouri A, Dob T, Belkebir A, Krimat S, Chelghoum C. Chemical composition and antioxidant activity of the essential oil and the methanol extract of Algerian wild carrot *Daucus carota* L. subsp. *carota*. J Mater Environ Sci. 2015;6(3):784-91.

14. Zatla AT, Dib MEA, Djabou N, Tabti B, Meliani N, Costa J, et al. Chemical variability of essential oil of *Daucus carota* subsp. sativus from Algeria. J Herbs Spices Med Plants. 2017;23(3):216-30. https://doi.org/10.1080/10496475.2017.1296053

15. Nakajima Y, Oeda K, Yamamoto T. Characterization of genetic diversity of nuclear and mitochondrial genomes in *Daucus* varieties by RAPD and AFLP. Plant Cell Rep. 1998;17(11):848-53. https://doi.org/10.1007/s002990050496

16. Hadjkouider B, Boutekrabt A, Lallouche B, Lamine S, Zoghlami N. Polymorphism analysis in some Algerian *Opuntia* species using morphological and phenological UPOV descriptors. Bot Sci. 2017;95 (3):391-400. https://doi.org/10.17129/botsci.887

17. Akbar F, Rabbani MA, Masood MS, Shinwari ZK. Genetic diversity of sesame (*Sesamum indicum* L.) germplasm from Pakistan using RAPD markers. Pak J Bot. 2011;43(4):2153-60.

18. Lallouche B, Hadj Kouider B, Beloudah A, Ben Madani R, Boutekrabt A. Phenotypic characterization of some lettuce cultivars (*Lactuca sativa* L.) cultivated in Algeria. Agrobiologia. 2020;10(1):1787-96.

19. Lallouche B, Hadjkouider B, Benmehaia R. The first assessment of phenotypic diversity in four quinoa (*Chenopodium quinoa* Willd.) populations cultivated in Algeria based on morphological traits. Ecol Eng Environ Technol. 2025;26 (6):275-85. https://doi.org/10.12912/27197050/204151

20. Kumari VN, Sivakumar S, Himakara DM. Multivariate analysis and multi-trait index-based selection of maize (*Zea mays* L.) inbreds for agromorphological and yield components. Plant Sci Today. 2025;e4206. https://doi.org/10.14719/pst.4206

21. UPOV. *Daucus carota* L. TG/49/8 Rev. Guidelines for the conduct of tests for distinctness, uniformity and stability. Geneva: International Union for the Protection of New Varieties of Plants; 2015.

22. IPGRI. Descriptors for wild and cultivated carrots *Daucus carota* L. Rome; 1998. p. 1-17

23. Williams WT. Pattern analysis in agricultural science. London: Pergamon Press; 1976.

24. Ward JH. Hierarchical grouping to optimize an objective function. J Am Stat Assoc. 1963;58(301):236-44. https://doi.org/10.1080/01621459.1963.10500845

25. Shannon CE, Weaver W. The mathematical theory of communication. Urbana: University of Illinois Press; 1949.

26. Al Khanjari S, Filatenko A, Hammer K, Buerkert A. Morphological spike diversity of Omani wheat. Gen Resour Crop Evol. 2008;55:1185 -95. https://doi.org/10.1007/s10722-008-9319-9

27. Grebenstein C, Kos SP, De Jong TJ, Tamis WLM, De Snoo GR. Morphological markers for the detection of introgression from cultivated into wild carrot (*Daucus carota* L.) reveal dominant domestication traits. Plant Biol. 2013;15 (3):531-40. https://doi.org/10.1111/j.1438-8677.2012.00662.x

28. Zdravkovska M, Agic R, Popsimonova G, Bogevska Z, Davitkovska M. Morphological characteristics and yield of carrot (*Daucus carota* L.) grown with application of microbiological fertilizers. J Agric Food Environ Sci. 2016;68:63-8.

29. Turner SD, Ellison SL, Senalik DA, Simon PW, Spalding EP, Miller ND. An automated image analysis pipeline enables genetic studies of shoot and root morphology in carrot (*Daucus carota* L.). Front Plant Sci. 2018;9:1703. https://doi.org/10.3389/fpls.2018.01703

30. Arif U, Aamir S, Khan MF, Siddiqui SU, Jatoi SA. Agro-morphological assessment and seed protein profiling in carrot (*Daucus carota* L.) germplasm. Pak J Bot. 2020;52(5):1825-33. https://doi.org/10.30848/PJB2020-5(7)

31. Char CD. Carrots (*Daucus carota* L.). In: Yahia EM, editor. Fruit and vegetable phytochemicals. 1st ed. Hoboken: Wiley; 2017. p. 969-78. https://doi.org/10.1002/9781119158042.ch46

32. Maksylewicz A, Baranski R. Intra-population genetic diversity of cultivated carrot (*Daucus carota* L.) assessed by analysis of microsatellite markers. Acta Biochim Pol. 2013;60(4):753-60. https://doi.org/10.18388/abp.2013_2053

33. Chaitra KC, Sarvamangala C, Manikanta DS, Chaitra PA, Fakrudin B. Insights into genetic diversity and population structure of Indian carrot (*Daucus carota* L.) accessions. J Appl Genet. 2020;61(3):303-12. https://doi.org/10.1007/s13353-020-00556-6

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