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CHARACTERISATION OF CARROTS OF VARIOUS ROOT COLOUR

OCENA ODMIAN MARCHWI O RÓŻNEJ BARWIE KORZENI

Abstract: Carrot (*Daucus carota* L.) is one of the main vegetables grown world-wide with orange roots occurring in Europe and purple, red, yellow and white in other world regions. Eight accessions were characterized with regard to their morphological traits, root yield and root chemical composition.

The most significant differences were observed in root colour, and colour homogeneity in flesh and core. The accessions differed in the proportion of marketable yield in total yield due to their different susceptibility to diseases, and the tendency to development of forked roots. Some populations produced bolters in the first year of cultivation, which additionally limited the number of marketable roots. Great variation was observed with regard to alpha- and beta-carotene as well as lutein content. Purple roots contained more lutein, and yellow roots had higher proportion of lutein to beta-carotene than roots of orange cultivars. Purple roots of carrot were particularly rich in phenolic compounds including anthocyanins, which corresponded with high antioxidant activity of root tissue extracts. The obtained results show valuable traits of coloured carrots, which are novel to European market, but also indicate on the need for the improvement of several characteristics of this crop before commercialization.

Keywords: anthocyanin, antioxidant activity, carotene, *Daucus carota* L., morphology, root yield

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Production of carrot (*Daucus carota* L. ssp. *sativus* Hoffm. Arc.) has tripled during recent 30 years and reached about 24 million tons ($24 \cdot 10^{12}$ g), with Europe covering about one quarter of world production [1]. Modern cultivars must now conform not only to high yield but also to advanced standard of root quality and nutritional value. The later is particularly important as carrots consumed raw or processed all-year-round is an important source of bioactive compounds, especially beta-carotene, a vitamin A precursor [2]. Roots of European cultivars are orange in colour, but this type of carrot emerged relatively recently around the 17th century. First edible carrots, probably developed in Afghanistan around 10th century, had yellow and purple roots, and they are still grown in Asia nowadays. Also white carrots are known in various world regions [3]. Root colour results from pigment composition, mainly carotenoids ie, orange beta-carotene and alpha-carotene, and yellow lutein, purple colour is determined by anthocyanins [4–6]. All these compounds are essential phytonutraceuticals of antioxidant activity and are important in prevention of cancer, cardiovascular diseases and age related dysfunctions [7, 8]. The composition and content of these compounds in carrot root is genetically determined by several main and accessory genes. Additionally, environmental factors influence their level [3, 9]. Few reports describing non-orange carrots are available till now indicating that yellow and purple carrots can be richer in bioactive compounds than orange roots [5, 10]. Utilization of these carrot types for production in temperate climate of Central Europe may be, however, not possible without further adaptation by breeding. They evolved in warmer climate or at the regions with longer day. Modified light conditions strongly affect plant reproductive biology, and as a result, Asian carrots grown in European conditions tend to flower in the first vegetation year, which disqualifies such plants for root production. Therefore, it is important to evaluate carrots of various root colours both for their nutritional value and suitability for commercial production.

Material and methods

Characterization of eight carrot (*Daucus carota* L.) accessions comprising commercial cultivars, and a breeding line was carried out in a field trial set up in an experimental station near Krakow (Poland). Seeds were sown (80 seeds $\cdot$ m^{-1}) in flat beds with two rows, each of 3 m long. Plots were arranged in a randomized block design with four replications. During vegetation the accessions were evaluated and characterized according to the list of IPGRI descriptors [11]. After harvest at 128 vegetation day, the same guideline was used for root description complementing yield assessment. Each harvested root was also classified into a marketable, small, forked, split or diseased fraction. Analyses of phenolic compounds and antioxidant activity were performed using 15 healthy, and untouched marketable roots from each field replication. Washed and homogenized root tissue samples were frozen and kept for analyses. Radical scavenging activity (RSA) was assessed by the reaction of 80 % MeOH root extract with DPPH (1,1-diphenyl-2-picrylhydrazyl) and measuring the absorbance after 30 min incubation [12]. The amount of total phenolics and anthocyanins was determined by measuring UV/VIS spectrum according to the method described by Fukumoto [13]. For carotenoid analysis, 10 roots were cut into cubes, lyophilized and milled. Acetonitrile/*n*-butanol extracts obtained using automated sample extractor were applied to Develosil RP-aqueous C30 (150 × 3 mm; 3 μm) column and analysed by HPLC-DAD (*diode array detector*). Alpha-carotene and lutein were monitored at $\lambda = 488$ nm and beta-carotene at $\lambda = 455$ nm. The data were subjected to one-way analysis of variance and the means were separated using a multiple range Duncan test at $p = 0.05$.

Results and discussion

Carrot cultivars of orange roots are common vegetable crop grown in Europe. We have compared two orange carrots, an old 'Nantes Fancy' and new developed F1 hybrid 'Nerac' with accessions of white, yellow and purple roots originating from various world regions. The most distinguished characters of these accessions are provided in Table 1. White, yellow and orange carrots were mostly homogeneous in colour both at skin along the root length and on a transverse section. Particularly, white and yellow roots had no colour difference between core and flesh, which is often observed in orange cultivars and considered as an undesirable trait. A great variation in colour was observed for 'Syrian Purple', which had purple flesh, but the core was not completely coloured and had white or yellow areas of various size. White carrots had very smooth skin surface although many lateral roots developed on storage roots of 'Blanche 1/2 longue des vosges'. For this trait, orange and yellow accessions were much more advanced as they showed very low number of lateral roots. Distinct morphological features of canopy, not observed in European carrots, were characteristic for 'Syrian Purple'. The leaves had unusual grey-green colour and were densely covered with long hairs on both sides of the lamina, similarly as the petioles. Another purple cultivar 'Anthonina' had strong anthocyanin pigmentation along the petioles.

A great variation was observed in root yield. Most accessions yielded in the range determined by two common orange cultivars (Table 1) ie 42–75 kg $\cdot$ 10 m^{-1}. Yield of yellow and white roots was superior to purple ones. Except modern orange hybrid 'Nerac' and old white 'Blanche 1/2 longue des vosges' a marketable yield was reduced by over 15 %. This was caused by a great share of roots classified as unmarketable, mainly forked. In particular, roots of 'Syrian Purple' were highly affected by bacterial diseases causing rotting in field conditions while yellow 'Gelbe Rhenische' developed large roots, which easily split probably due to prolonged vegetation period. Additionally, emergence of shoots with inflorescences limited the number of plants suitable for root production. A remarkable number of bolters in the first year of cultivation was observed in 'Syrian Purple' (over 3 %), which is not adopted to long day conditions while other accessions flowered with a frequency below 1 %. None of the orange cultivars developed shoots with inflorescences.

The biochemical parameters varied depending on the accession evaluated (Table 2).

Orange cultivars contained 26–38 mg phenolic compounds in 100 g root tissue and very low amounts of anthocyanins (below 1 mg $\cdot$ 100 g^{-1} f.m.). Similar level was also found in white and yellow cultivars, which did not differ significantly to each other with

Table 1

Root yield and morphological characters of evaluated carrot accessions

Accession Origin/propagator	Type	Skin colour	Flesh colour	Core colour	Root surface	Lateral roots	Yield [kg · 10 m^{-2}]	Yield structure [%]			
								Marketable roots	Split roots	Diseased roots	Bolters
Blanche 1/2 longue des vosges INH / JKI	old French cultivar	white	white	white	smooth	medium	68.74 ± 2.3 cd	92.5	0.5	0	0.14
Kuettiger HRIGRU / JKI	old Swiss local cultivar	white	white	white	smooth/light dimpled	medium	55.83 ± 3.7 bc	85.8	1.0	1.7	0.2
Gelbe Rheinische HRIGRU / JKI	old German cultivar	yellow	yellow	yellow	light dimpled	low	64.43 ± 3.5 cd	82.1	2.4	2.1	0.0
Line 710015 Seminis	modern breeding line	yellow	yellow	yellow	smooth/light dimpled	low	119.34 ± 8.7 e	83.6	1.3	0.2	0.2
Anthonina Seminis	modern cultivar	purple	purple	purple/yellow purple/white purple	medium/strong ringed	medium	58 ± 2.3 c	87.2	0.5	0.4	0.8
Syrian Purple HRIGRU / JKI	Syrian landrace	purple	purple	white/yellow purple/white purple	strong ridged	medium	39.8 ± 2.6 a	82.1	0.0	8.4	3.1
Nantes Fancy NGB / JKI	old cultivar	orange	orange	orange	light/medium dimpled	low	42.34 ± 3.2 ab	83.3	0.0	1.1	0.0
Nerac Bejo Zaden	modern F1 hybrid	orange	orange	orange	light dimpled	low	75.1 ± 3.5 d	94.1	0.8	0.0	0.0

Explanation: HRIGRU – Horticulture Research International Genetic Resources Unit, Warwick, UK; INH Institut National d'Horticulture, Angers, FR; JKI – Julius Kuehn Institute, Quedlinburg, DE; NGB – Nordgen Plants, Alnarp, SE; Means followed by the same letter in a column do not differ significantly at $p = 0.05$.

regard to those components. In contrast, both purple carrots possessed elevated amounts of anthocyanins additionally accompanied by other phenolics, which in total reached the level of 130 and 290 mg · 100 g^{-1} f.m. in 'Syrian Purple' and 'Anthonina', respectively. The presence of phenolics and anthocyanins highly correlated with the root extract ability to neutralize free radicals (0.99 and 0.97, respectively), so both purple cultivars showed very high antioxidant activity. On the other hand, roots of other colours did not show any antioxidant activity or exhibited a tendency for a prooxidant activity like the line 710015. The presence of phenolic compounds in plant tissue may increase nutritional value of fruits and vegetables because of their antioxidant properties [14]. Particularly flavonoids, like anthocyanins, are considered as valuable in protection against reactive oxygen species [15].

Table 2

Chemical composition and radical scavenging activity (RSA) of carrot root tissue [mg · 100 g^{-1} fresh mass]

Accession	Lutein	Alpha--carotene	Beta--carotene	Total phenolics	Antho-cyanins	RSA [%]
Blanche 1/2 longue des vosges	0.02 ± 0.01* a	0.1 ± 0.01 a	1.5 ± 0.1 a	31.0 ± 0.8 a	0.4 ± 0.1a	–0.5 ± 0.3 b
Kuettiger	0.04 ± 0.02 a	0.1 ± 0.02 a	2.1 ± 0.1 a	28.2 ± 1.4 a	0.1 ± 0.03 a	–2.1 ± 0.2 ab
Gelbe Rheinische	0.9 ± 0.03 b	0.2 ± 0.10 ab	6.2 ± 1.6 ab	27.7 ± 0.8 a	0.4 ± 0.02 a	0.6 ± 0.2 b
Line 710015	0.7 ± 0.06 b	0.1 ± 0.02 a	4.3 ± 0.5 ab	22.2 ± 1.0 a	0.1 ± 0.1a	–7.0 ± 0.4 a
Anthonina	2.5 ± 0.27 d	1.6 ± 0.40 c	23.6 ± 6.2 cd	290.2 ± 18.3 c	65.6 ± 7.4 c	61.5 ± 2.7 d
Syrian Purple	1.7 ± 0.25 c	0.1 ± 0.02 bc	16.2 ± 2.9 bc	129.6 ± 7.0 b	14.2 ± 1.2 b	24.3 ± 3.0 c
Nantes Fancy	1.0 ± 0.05 b	3.5 ± 0.30 e	48.7 ± 6.9 e	38.1 ± 2.8 a	0.4 ± 0.04a	–2.8 ± 0.6 ab
Nerac	0.8 ± 0.04 b	2.4 ± 0.10 d	30.0 ± 1.3 d	25.6 ± 1.2 a	0.3 ± 0.1a	–1.8 ± 0.1 ab

* Mean values with standard errors; Means followed by the same letter in a column do not differ significantly at $p = 0.05$.

Carotenoids were detected in all roots (Table 2). Orange ones contained these compounds in the amounts of 32–52 mg · 100 g^{-1} f.m. with xanthophylls (alpha--carotene and lutein) contributed about 10 % of beta-carotene level, and with lutein to alpha-carotene ratio of 1 to 3. Purple and yellow roots had two- and six-fold lower amounts of carotenoids than orange roots, respectively. However they contained two-fold higher proportion of both xanthophylls to beta-carotene. Particularly rich in lutein were purple carrots possessing 1.7 and 2.5 mg · 100 g^{-1} f.m. Thus in contrast to common edible carrots considered rather as a poor source of lutein, purple roots may provide a substantial portion of a recommended allowance, which is proposed to be 6 mg per day [16]. White roots were almost free of carotenoids as reported previously [17]. Although carotenoids are known as strong antioxidants, there was no correlation found between the content of these compounds and RSA. This discrepancy results from the analytical method used. The DPPH assay is convenient for the assessment of antioxidant activity of phenolics but not carotenoids, which spectra interfere with DPPH [18].

Vegetable consumption is recommended to limit numerous civilisation diseases initiated by reactive oxygen species (ROS), which are generated either during the normal cell function or result from environmental pollution [19]. Carrots possess carotenoids and phenolic compounds functioning as ROS antagonists. Our study shows that purple coloured roots are particularly rich in anthocyanins and other phenolics as well as in lutein, the macular pigment of human retina, which deficiency leads to age-related macular degeneration [20]. Also yellow coloured roots may contain a high proportion of lutein. These properties makes coloured carrots valuable source of health promoting compounds superior to orange cultivars. They may also become attractive to consumers due to their root colour, which is unusual at European market. Purple roots additionally may become a source of monoacylated anthocyanins, which possess increased stability at food pH, during heating and storage, and are advantageous for food colouring in comparison with anthocyanins produced from red grape or berries [21]. However utilization of such types for commercial production requires the development of advanced, highly uniform populations with high marketable yield. Our field trials indicate that the accessions grown in other world regions are not suitable for direct implementation into commercial production and require improvement through breeding programs. Among the most crucial traits to be enhanced are resistance to diseases and root homogeneity as well as reducing the number of forked roots and bolting tendency.

Conclusions

Carrot accessions of various root colour and origin were grown in temperate climate of Poland and compared with regard to their morphological traits, yield and chemical composition. The results indicate that accessions with other than orange root colour may: 1) possess valuable compounds ie, yellow and purple roots contain high proportion of lutein in total carotenoids, and purple roots have high content of antioxidants, including anthocyanins, 2) exhibit undesirable characters like tendency for bolting, high share of forked roots and susceptibility to diseases, which make them difficult for direct commercialization.

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Abstrakt: Marchew jadalna (*Daucus carota* L.) jest jednym z głównych warzyw uprawianych na świecie. W Europie znana jest głównie marchew o korzeniach pomarańczowych, natomiast w innych rejonach świata również o korzeniach fioletowych, czerwonych, żółtych i białych. W niniejszej pracy scharakteryzowano osiem odmian i linii pod względem różnych cech morfologicznych, plonu oraz składu chemicznego korzeni.

Największe zróżnicowanie zaobserwowano ze względu na barwę oraz stopień ujednolicenia barwy miąższu i rdzenia. Badane obiekty różniły się udziałem korzeni handlowych w plonie całkowitym, co wynikało z ich zróżnicowanej podatności na choroby oraz tendencji do wytwarzania korzeni rozwidlonych. Niektóre populacje wytwarzały kwiatostany w pierwszym roku uprawy, co dodatkowo obniżało plon korzeni handlowych. Zaobserwowano duże zróżnicowanie pod względem zawartości alfa- i beta-karotenu oraz luteiny. Marchew o korzeniach fioletowych zawierała więcej luteiny natomiast żółte miały więcej luteiny w stosunku do beta-karotenu w porównaniu z marchwią pomarańczową. Marchew o korzeniach fioletowych zawierał więcej związków fenolowych, w tym antocyjany, co korespondowało ze zwiększoną aktywnością antyoksydacyjną tkanki korzeniowej. Uzyskane wyniki potwierdzają korzystne cechy marchwi kolorowych, będących nowością na rynkach europejskich, jednocześnie wskazując na potrzebę poprawy niektórych cech przed wprowadzeniem ich do uprawy na skalę komercyjną.

Słowa kluczowe: aktywność antyoksydacyjna, antocyjany, *Daucus*, karoten, morfologia, plon korzeni