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SOME ASPECTS OF NUTRITIVE AND BIOLOGICAL VALUE OF CARROT CULTIVARS WITH ORANGE, YELLOW AND PURPLE-COLOURED ROOTS

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Summary

The aim of this work was to determine antioxidant activity and some physical and chemical parameters influencing nutritive and biological value of orange, purple and yellow carrot cultivars. The two-year experiment was carried out in Warsaw Agricultural University in 2005 and 2006. Carrot was grown in the experimental field of the University. Six carrot cultivars, differed in storage roots colour and shape, were chosen for the experiment: 'Florida' F_1, 'Interceptor' F_1, 'Nebula' F_1, 'Purple Haze' F_1, 'Yellowstone', 'Mello Yello' F_1. Immediately after harvest of carrots there were determined: dry matter, total sugars content, total phenolics, total carotenoids, antioxidant activity (DPPH), fractions of dietary fibre, pectines, pH, redox potential, electrical resistance. P-value, which is a combined parameter of some physical and chemical traits, was also calculated. Correlations between some of these quality parameters were determined. Dry mater content was the highest for 'Purple Haze' in 2005, but in 2006 for 'Nebula' similar dry matter content was found. Total sugars content in carrots in 2005 was the highest in 'Purple Haze' but in 2006 'Florida' showed higher sugars content. Total phenolics content was the highest in 'Purple Haze' roots. Total carotenoids content was greatly differentiated between cultivars and varied from below 1 mg·100 g^{-1} to above 14 mg·100 g^{-1}. For cultivars of yellow storage roots the lowest level of carotenoids were found, and the highest for orange-coloured 'Florida', 'Interceptor' and 'Purple Haze'. In all cultivars, from fractions of total fibre, the highest amount was found in the case of cellulose and pectines. The highest antioxidant activity showed purple-coloured cultivar 'Purple Haze', and the lowest activity yellow-coloured cultivars 'Yellowstone' and 'Mello Yello'. Regression analysis showed that antioxidant activity of carrot storage roots was strictly related to carotenoids content (r=0.92) and phenolics content (r=0.87).

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key words: antioxidant activity, carrot, chemical composition, cultivars, nutritive value

INTRODUCTION

Carrot (*Daucus carota* L.) is one of the main vegetable crops grown in temperate climate regions. Carrot originates from the wild forms growing in Europe and southwestern Asia. The first cultivated carrot types were purple or violet. Later yellow and orange types were derived from this anthocyanin type, by selection process (Banga 1984). The western type of cultivated carrot is thought to derive from the anthocyanins-containing forms found in Afghanistan. Consumption of carrot has increased last years, mainly due to high biological value of this vegetable. Poland is the second country in Europe in respect of total production of this vegetable. Most carrot cultivars grown in Europe belong to orange-colour type, but several new cultivars of other root colour exist: creamy-white, yellow, purple and violet.

According to Mazza (1989), the most important quality attributes for carrot are size, shape, uniformity, colour, texture and internal aspects (sensory quality and biological value). The main biological value relates to vitamins and dietary fibre content in roots (Alasavar *et al*. 2005). Soluble sugars are the main storage compounds in carrot roots. They account for 35-70% of dry weight of the root and are stored in the vacuoles of the parenchyma (Nilsson 1987). Sucrose is the predominant storage sugar at root maturity, which amount reaches 3.6% (Daie 1984). According to Holden *et al.* (1999) raw carrots contain 12% of dry matter, 4.5% of sugars, 2% of dietary fiber, 5.7 mg·100 g^{-1} of β-carotene, 5.9% of vitamin C. Chemical composition of carrot root is affected by cultivar, growing conditions and storage (Warman & Havard 1997). Recently, purple- and yellow-coloured cultivars appeared on European market. These forms had been bred from Asian lines (Rubatzky *et al.* 1999). Purple carrots contain higher amount of phenolics, mainly anthocyans, and show higher antioxidant capacity (Alasalvar *et al.* 2005). Also lycopene was found in Asian lines (Mayer-Miebach & Spiess 2003).

Scientists and consumers pay increasing attention to chemical compounds, which show health promoting properties. With this regards, antioxidants are of special interest. Antioxidants are compounds that inhibit or delay the oxidation of other molecules and protect cells against the damaging effects of reactive oxygen species. Antioxidant acivity of several plant products has been reported (Velioglu *et al.* 1998, Paulauskiene *et al*. 2006, Podsędek 2007). Natural antioxidants can be phenolic compounds (e.g. tocopherols, flavonoids and phenolic acids), nitrogen compounds (e.g. alkaloids, chlorophyll derivates, amino acids and amines), carotenoids and ascorbic acid. These compounds are commonly found in fruits and vegetables (Wu *et al.* 2004). Products high in vitamin A, vitamin C, vitamin E, and β-carotene are believed to be the most beneficial. However, little is known about the antioxidant activity and phytonutrients in either orange or purple carrots. Purple carrots contain higher amounts of anti-

oxidant vitamins, carotenoids and phenolics (Alasalvar *et al*. 2005) than other coloured carrot varieties (orange, yellow and white).

Carotenoids are red, orange or yellow fat-soluble plant pigments. In human organism, carotenoids play two primary roles: exert antioxidant activity, but some are also converted into the vitamin A. Of 600 carotenoids that have been identified, about 30 to 50 are believed to have vitamin A activity (Handelman 2001). The best known of this group are β-carotene and α-carotene. Experimental studies suggest that a higher dietary intake of carotenoids protects against certain cancers, macular degeneration, cataracts, and other health conditions involved with oxidative or free radical damage (Rock 1997). Special physiological activity of these compounds causes increasing interest in determining their content in different products. Carrots are believed to be a good source of carotenoids. The main carotenoids found in carrots are α-carotene and β-carotene. Of about 5.7 mg·100 g^{-1} of carotenes in carrot, α-carotene and β-carotene account for more than 90% (Simon & Wolff 1987). Skrede *et al.* (1997) found that high β-carotene content results in a more reddish and darker root colour but a less intensive hue. β-carotene content increases with the age and size of the carrot storage root (Rubatzky *et al.* 1999).

It was found that polyphenolic acids are very active antioxidants, slow down the release of glucose into the bloodstream after a meal and inhibits tumor promoting activity of phorbol esters (Sawa *et al.* 1999, Ismail 2004). They have also immunostimulating and antibacterial activity and increase plant resistance to some pathogens. Changes in phenolic compounds content in some vegetable species, resulted from pre- and postharvest factors, were investigated by several authors (Babic *et al.* 1993, Leja *et al.* 1995, 1997, Gajewski & Rosłon 2002). In carrot storage roots phenolics accumulation during storage at ambient atmosphere was observed (Leja *et al.* 1995).

Electrochemical methods provide additional information about metabolism and physiological processes. Life processes in plants can be described as chains of electro-chemical or redox reactions. Scientists developed a bioelectrical theory to derive electrical energy value of food from measurements of pH, redox potential and electrical resistance. They suggest that food with low P-value, which is a combined parameter of three mentioned parameters above, is health promoting (Bloksma *et al.* 2001). Application of electrochemical research methods provides the possibilities to evaluate vitality of system and plant suitability for food (Danilcenko *et al.* 2005).

The definition of dietary fibre from a nutritional perspective is based on non-digestibility of oligo- and polysaccharides (and their hydrophilic derivatives) in the small intestine (Green 2001). Fibre is not a simple and well defined chemical compound but a combination of chemical substances of distinct composition and structure, such as cellulose, hemicelluloses, lignin (Rodriguez *et al.* 2006). Carrot is believed to be a good source of dietary fibre.

Genetic variation and environmental conditions largely influence chemical composition of carrot. For example, growing and storage conditions affect the level of volatiles, sugars and carotenoids (Lee 1986, Seljasen *et al.* 2001, Ga-

jewski & Dąbrowska 2007). During storage of carrot increasing hexose and decreasing sucrose content was observed (Suojala 2000). Bitter taste of carrot is sometimes observed during storage and it is caused by accumulation of 6-methoxymellein (Seljasen *et al.* 2001).

The aim of this work was to determine antioxidant activity, and some physical and chemical parameters influencing nutritive and biological value of orange, purple and yellow carrot cultivars.

MATERIAL AND METHODS

The experiment was carried out in Warsaw Agricultural University in 2005-2006. Carrot was grown on the experimental field of the University. The soil in the field was a medium mud soil. Carrots were sown directly to the ground on ridges at the end of May, and plants were harvested at full maturity, in the middle of October. Fertilizing of the field was applied according to soil analysis results. Data concerning temperature and rainfalls during the growing season are presented in Table 1. In the first year mean temperatures for the period June-September were higher than mean temperatures for the period 1931-1990. In the next year, high mean temperature for August was noted. This month in 2006 was very poor in respect of rainfalls.

Table 1. Temperature and rainfalls in both years of the experiments (2005, 2006), and means for 1931-1990

Month	Temperature (^{o}C)			Rainfalls (mm)		
	2005	2006	Means 1931-1990	2005	2006	Means 1931-1990
June	16.8	16.3	16.9	56.0	68.7	67.8
July	21.0	22.3	18.1	74.7	42.7	66.5
August	18.6	19.2	17.6	8.6	28.7	65.7
September	16.6	15.2	13.5	32.6	46.9	43.1

Six cultivars of different storage root colour and shape were chosen - 'Florida' F_1, 'Interceptor' F_1, 'Nebula' F_1, 'Purple Haze' F_1, 'Yellowstone', 'Mello Yello' F_1. Characteristics of cultivars: 'Florida' - roots orange-coloured cylindrical, 'Interceptor' - roots orange red-coloured, elongated; 'Nebula' - roots orange-coloured, cylindrical; 'Purple Haze' - roots purple-coloured, with orange core; 'Yellowstone' - roots yellow-coloured; 'Mello Yello' - roots yellow-coloured.

Dry matter was determined by drying samples in 105^{o}C, until stable weight. Total sugars were determined by Luff-Schoorl's method. Electrochemical properties of root tissue were determined in homogenized fresh roots samples. The pH value was determined according to the standard LST/ISO 1842:1997, redox potential by ionometer Metrohm AG CH-9101, electrochemical conductivity by conductometer (the conductivity is the inverse of electrical resistance). P-value (as combined parameter of the three mentioned parameters) was used for evaluation of carrots quality, and calculated according to the for-

mula (Meier-Ploeger & Vogtmann 1988): $P = [29.07 \text{ mV } (rH - 2pH)]^2 \cdot rho^{-1}$ (μW); where: rH – redox potential (mV), rho – electrical resistance (Ohms)

Antioxidant activity was determined spectrophotometrically, according to Yen & Chen (1995), as the percent of DPPH (2,2-diphenyl-1-picrylhydrazyl) activity inhibition in plant flesh methanol extract. Samples of carrots (5 g) were grounded and extracted for 30 min in methanol. Measurements were done after 10 minutes of reaction period, using the wavelength 517 nm. Carotenoids content was determined by spectrophotometrical method (Lichtenthaler and Wellburn 1983). Deeply frozen samples (5 g) were grounded with 30 g of anhydrous sodium sulfate and extracted for 12 hours by 50 ml of hexane. Total carotenoids content were determined by the Shimadzu spectrophotometer, using the wavelength 450 nm. Total phenolics content was determined spectrophotometrically, using the Folin-Ciocalteau reagent (Ragazzi & Veronese 1973). Total neutral fibre (NDF) content and its fractions were determined according to detergent's method (Georing & Soest 1970). Pectines content in carrot roots was determined according to method described by King (1987).

All analyses and measurements were done on representative samples taken in three replicates from fresh plant material. For the analysis of variance Statgraphics Plus 4.1 software was applied, and Tukey's test was used to show which values differ significantly at P=0.05. In order to find relationship between data, regression analysis was applied.

RESULTS AND DISCUSSION

Cultivars chosen for the experiment showed big differentiation in respect of almost all quality parameters determined. Moreover, the influence of season conditions on the results was observed in the case of most cultivars, so data obtained are presented for both years of the study. Dry mater content was the highest for 'Purple Haze' in both years, but in 2006 similar dry matter content as in 'Purple Haze' was found for 'Interceptor' (Fig. 1). Total sugars content in both years was the highest in 'Purple Haze' (Fig. 1), so this could be the reason of high dry matter content found for this cultivar. High sugars content could be also the reason of a big intensity of sweet taste of this cultivar (Gajewski & Dąbrowska 2007). In 2005 'Florida' showed also high sugars content, but not as high as 'Purple Haze'. 'Interceptor' and 'Yellowstone' had relatively lower sugars content in both years. All other cultivars showed similar level of sugars content, but differences between years of the study were quite big, with the except of 'Yellowstone' and 'Nebula', which had similar sugars content in both years.

Total phenolics content was the highest in 'Purple Haze' in both years of the study (Fig. 2). This high content of phenolic compounds can be explained by colour characteristics of the cultivar, which is purple in the outer part of storage root. Antocyanins, which cause purple colour, belong to phenolic compounds (Alasalvar *et al*. 2005). High phenolics content in purple-coloured cultivar could be the reason of high antioxidant activity of its roots. The correlation between phenolics content and antioxidant activity of vegetables are reported in literature, but no strict relationship was found (Ismail *et al.* 2004).

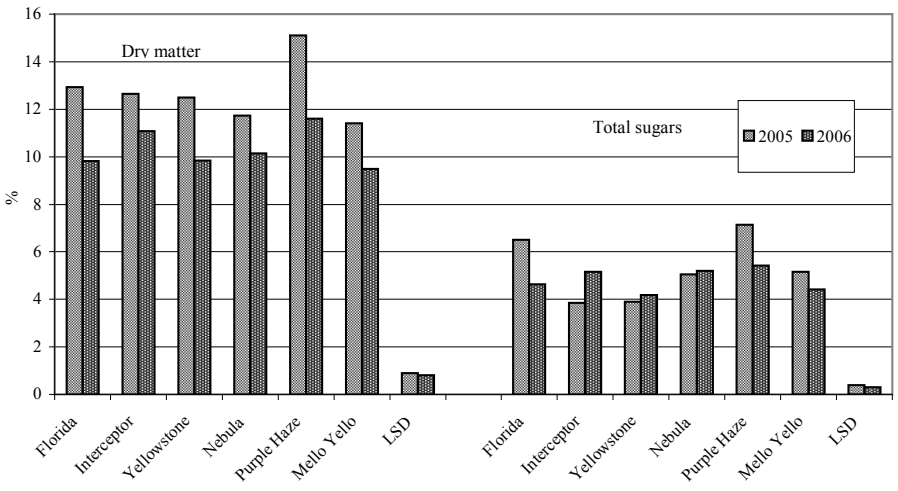


Fig. 1. Dry matter and total sugars content in carrot cultivars in both years of the experiment

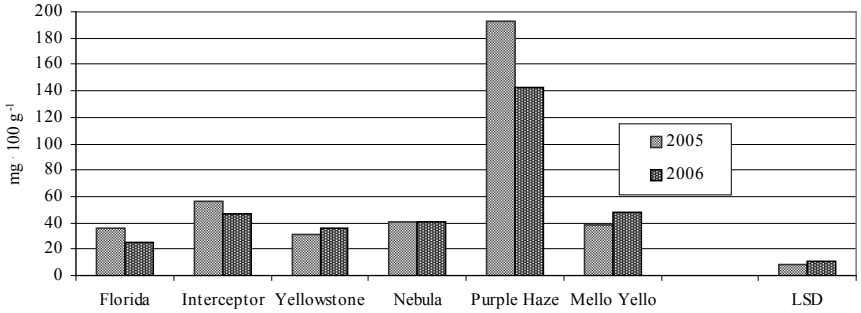


Fig. 2. Total phenolics content in roots of carrot cultivars in both years of the experiment

Carrot roots as well as winter squash fruits are one of the best sources of carotenoids. According to Holden *et al.* (1999) carrots contain 5.7 mg·100 g^{-1} of β-carotene, and winter squash contains 0.4-7.5 mg·100 g^{-1} of α-carotene and 1.4-8.4 mg·100 g^{-1} of β-carotene, depending on cultivar (Holden *et al*. 1999, Gajc-Wolska *et al*. 2005, Seroczyńska *et al.* 2006). In this experiment total carotenoids content was greatly differentiated among cultivars and varied from below 1 mg·100 g^{-1} to above 14 mg·100 g^{-1} (Fig. 3). The lowest values for yellow cultivars were found, and the highest for 'Florida', 'Interceptor' and 'Purple Haze'. Results obtained for 'Purple Haze' indicate that purple-coloured roots are also a good source of carotenoids, not only phenolic compounds.

Antioxidant activity was highly differentiated (Fig. 4). This parameter is very important from nutritive point of view, since carrots are consumed as a

valuable source of some biologically active compounds, including antioxidants. The highest antioxidant activity showed purple-coloured cultivar 'Purple Haze', and the lowest activity – yellow coloured cultivars 'Yellowstone' and 'Mello Yello'. It confirms the opinion that purple-coloured carrots have higher amount of antioxidants than typical, orange-coloured ones. It is believed that this phenomenon is related to higher phenolic compounds level in purple-coloured cultivars.

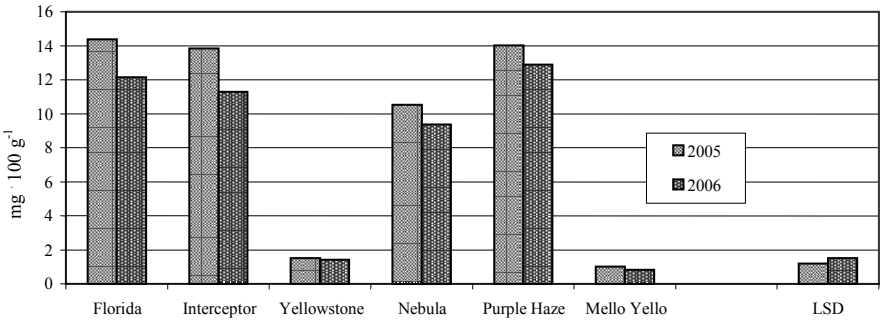


Fig. 3. Total carotenoids content in carrot cultivars in both years of the experiment

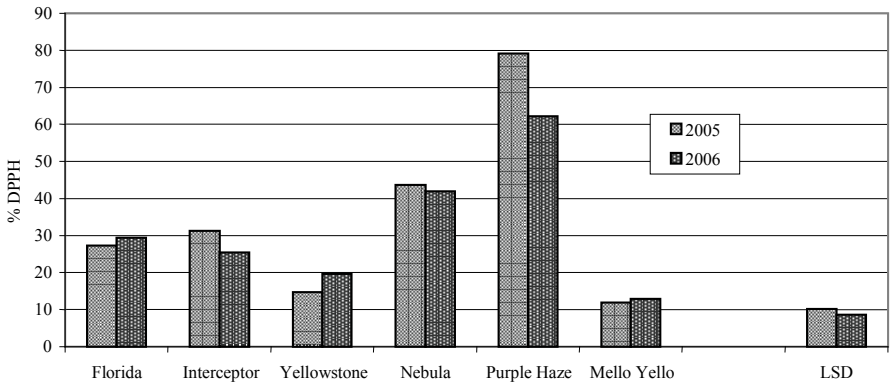


Fig. 4. Antioxidative activity of roots of carrot cultivars in both years of the experiment

All carrot cultivars contained high amount of total dietary fibre (Fig. 5). From fractions of total fibre the highest level was found in the case of cellulose and pectines fractions. The highest level of these fractions was found in 'Mello Yello' (Fig. 6). This cultivar was also the richest in neutral dietary fibre (NDF) (above 12% of d.m.) (Fig. 7). Pectines, as well as NDF, are a very valuable component of food, since their role in prevention of colon diseases is underlined in medicine (Green 2001).

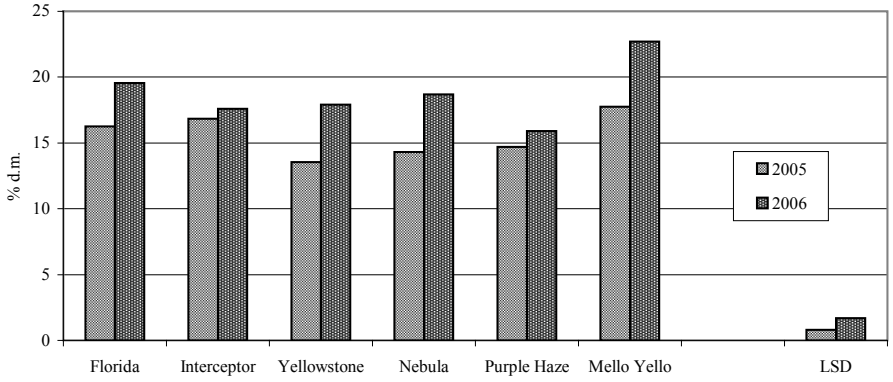


Fig. 5. Total dietary fibre content in carrots cultivars for both years of the experiment

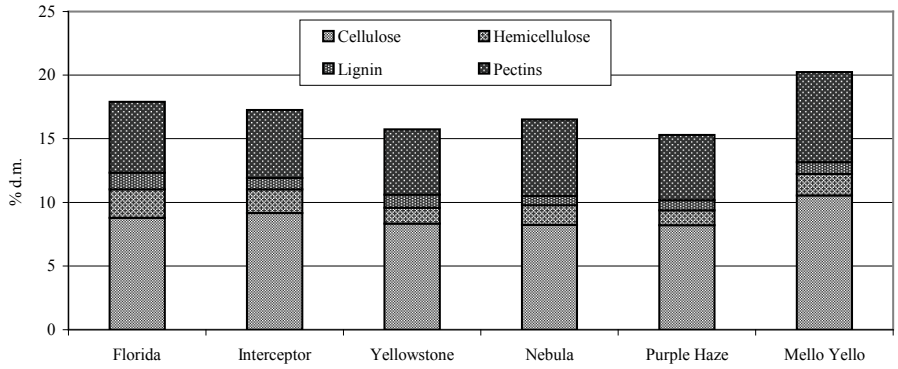


Fig. 6. Fractions of total dietary fibre in carrot cultivars, means of both years of the experiment

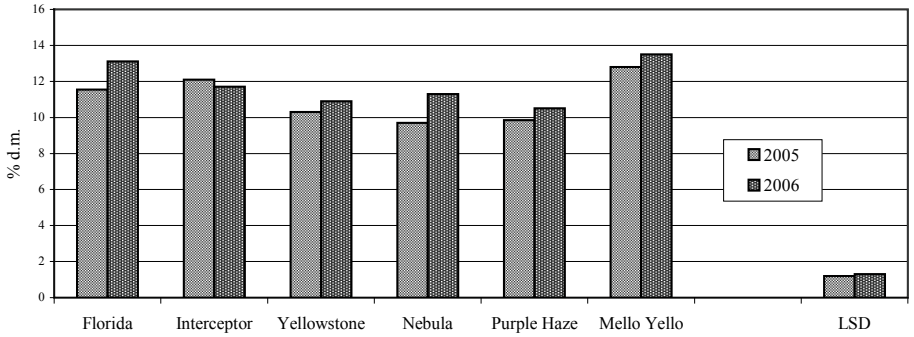


Fig. 7. Neutral diietary fibre content in carrot cultivars for both years of the experiment

Electrochemical parameter pH is usually used to determine acidity of the plant flesh. This parameter shows the level of activity of ions and expresses energetic aspects of life process. The increase of pH means a loss of vitality in plants (Danilcenko *et al.* 2005). The pH values were little differentiated in the cultivars, between 6.0 and 6.5 (Table 2). This point out a low level of acidity of storage root tissues. Redox potential is other important electrochemical parameter and it reflects the intensity of oxidation-reduction reactions. When redox potential in tissue is low, the plant cells can use freer enthalpy for their activity. Redox potential was the lowest for 'Purple Haze' and 'Mello Yello' (Table 2). Orange-coloured cultivars showed tendency to slightly higher redox potential than other ones. High values of electrical resistance indicate that electrolytes and other cellular ions are more integrated in membranes and cell organelles. Low values indicate the abundant presence of free-moving electrolytes, what might be a sign of deterioration of plant cells and tissues (Bloksma *et al.* 2001). Electric resistance of carrots varied from 82 to 106 ohms and was the highest for 'Florida' (Table 2). To compare these values, pumpkin fruits showed resistance from 77 to 314 Ohms (Paulauskiene *et al*. 2006).

Table 2. Physicochemical characteristics of carrot cultivars

Year of study	Cultivar	pH	rH Redox potential (mV)	Electrical resistance (Ω)	P-value (μW)
2005	Florida	6.26a	20.9b	116.2d	510.7c
	Interceptor	6.19a	20.4b	84.9a	640.2d
	Yellowstone	6.14a	19.6a	94.5b	479.2c
	Nebula	6.24a	20.1ab	103.4c	474.5c
	Purple Haze	6.27a	16.3a	106.8c	111.8a
	Mello Yello	6.22a	18.7a	89.8ab	368.7b
2006	Florida	6.34b	20.5c	113.8e	454.1c
	Interceptor	6.21ab	20.6c	82.7a	683.7e
	Yellowstone	6.15a	20.6c	100.4cd	579.8d
	Nebula	6.28b	20.0c	109.2de	428.3c
	Purple Haze	6.29b	16.0a	82.3a	96.6a
	Mello Yello	6.22ab	18.0b	83.3a	313.6b

Note: values for years which do not differ according to Tukey's test at P=0.05 are marked with the same letters

According to Bloksma *et al.* (2001), P-value is used to define vitality of the organisms, energy distribution tendencies, and indicates corresponding entropy of the system. Higher P-value can be interpreted as more openness, while lower values indicate ordering or coherence. Literature indicates that the lower is P-value, the more the product is suitable as food and it is healthier from nutritive aspect. The lowest P-value in both years was found for 'Purple Haze' roots (below 100 μW) (Table 2). Orange-coloured cultivars had the highest value of P.

It was found that correlation between antioxidant activity and carotenoids content is equal to 0.92, between antioxidant activity and total phenolics content is equal to 0.87 (Table 3). Correlations between redox potential and these compounds were insignificant. These relationships show that antioxidant activity of carrot roots is strictly related to carotenoids content, but also phenolics content. So, purple-coloured cultivar, which is richer in phenolic compounds, is also very valuable as a source of antioxidants. The correlation between redox potential and phenolics content was also significant, but in the case of carotenoids content was unsignificant. Similar strong relationship between carotenoids content and antioxidant activity was also found for pumpkin fruit (r=0.91) (Paulauskiene *et al.* 2006). There was also found a strong positive correlation between P-value and phenolics content.

Table 3. Correlation coefficients *r* between chemical compounds in carrot roots and antioxidant activity (DPPH) and redox potential of flesh

Compounds	Antioxidant activity	Redox potential	P-value
Carotenoids	0.92*	–0.12	0.31
Phenolics	0.87*	0.45	0.93*

Note: * means significant correlation at P=0.05

CONCLUSIONS

1. Investigated carrot cultivars of orange, purple and yellow storage roots differ in chemical and physical quality parameters, including dry matter, total sugars, total phenolics, total carotenoids, antioxidant activity (DPPH), pH, redox potential, electrical resistance, fibre content and composition.
2. Yellow coloured carrot cultivars are poor in carotenoids content, and purple coloured one is rich in phenolic compounds.
3. Cellulose and pectines are the main fractions of total dietary fibre found in carrots roots. The highest amount of these fractions was found in ‘Mello Yello’. This cultivar was the richest cultivar in the case od NDF amount.
4. Antioxidant activity of carrot roots is strictly related to carotenoids content, but also phenolics content.

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NIEKTÓRE ASPEKTY WARTOŚCI ODŻYWCZEJ I BIOLOGICZNEJ ODMIAN MARCHWI O POMARAŃCZOWEJ, ŻÓŁTEJ I FIOLETOWEJ BARWIE KORZENI

Streszczenie

Celem pracy było określenie aktywności antyoksydacyjnej oraz niektórych parametrów fizycznych i chemicznych wpływających na wartość odżywczą i biologiczną odmian marchwi o pomarańczowych, fioletowych i żółtych korzeniach. Doświadczenie przeprowadzono w Szkole Głównej Gospodarstwa Wiejskiego w latach 2005-2006. Marchew pochodziła z uprawy na polu doświadczalnym SGGW. W doświadczeniu uwzględniono sześć odmian różniących się barwą i kształtem korzeni: ‘Florida’ F_1, ‘Interceptor’ F_1, ‘Nebula’ F_1, ‘Purple Haze’ F_1, ‘Yellowstone’, ‘Mello Yello’ F_1. Bezpo-

średnio po zbiorze określano: suchą masę, cukry ogółem, związki fenolowe ogółem, karotenoidy ogółem, aktywność antyoksydacyjną (metodą DPPH), błonnik pokarmowy i jego skład, związki pektynowe, pH, potencjał oksydoredukcyjny, elektroprzewodnictwo. Obliczono także wartość P, która jest parametrem jakości kalkulowanym na podstawie cech fizycznych. Określono korelacje między niektórymi z tych parametrów. Zawartość suchej masy była najwyższa obu latach w korzeniach odmiany 'Purple Haze' w 2005 r., ale w 2006 r. podobną zawartość suchej masy stwierdzono w odmianie 'Nebula'. Zawartość cukrów ogółem w 2005 r. była najwyższa w odmianie 'Purple Haze', natomiast w 2006 r. w odmianie 'Florida'. Ogólna zawartość związków fenolowych była najwyższa w korzeniach odmiany 'Purple Haze'. Zawartość karotenoidów była bardzo zróżnicowana i wahała się od poniżej 1 mg·100 g^{-1} do ponad 14 mg·100 g^{-1}. Najniższą zawartość karotenoidów stwierdzono u odmian o żółtym korzeniu, natomiast największą u odmian 'Florida', 'Interceptor' i 'Purple Haze'. Badane odmiany marchwi różniły się zawartością błonnika pokarmowego i jego frakcji. Dominującymi frakcjami, niezależnie od odmiany, były frakcja celulozowa i pektynowa. Największą aktywność antyoksydacyjną wykazywały korzenie fioletowej odmiany 'Purple Haze', a najmniejszą korzenie żółto zabarwionych odmian 'Yellowstone' i 'Mello Yello'. Analiza regresji wykazała, że aktywność antyoksydacyjna jest ściśle związana z zawartością karotenoidów (r=0.92) i związków fenolowych (r=0.87) w korzeniach.