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The influence of controlled atmosphere storage on selected quality traits of carrot cultivars with different root colours

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Abstract: *The influence of controlled atmosphere storage on selected quality traits of carrot cultivars with different root colours.* Carrot cultivars with various root colours are gaining popularity in Europe. Most such crops need to be stored for a period of several months, which causes quality degradation. The objective of the study was to determine the influence of long-term cold storage under different atmospheric compositions on certain physical and chemical quality parameters of carrots of various colours. Carrots with orange (‘Nebula’ F_1, ‘Perfekcja’, ‘Interceptor’ F_1), purple-orange (‘Purple Haze’), purple (‘Deep Purple’ F_1), yellow (‘Mello Yello’) and white (‘White Satin’ F_1) roots were stored for 6 months in a cold store at a temperature of 0–1°C and 95% RH, under controlled atmosphere (CA) with the following gas compositions: 5% CO_2 + 10% O_2, 2% CO_2 + + 5% O_2, 5% CO_2 + 5% O_2 and 0% CO_2 + 21% O_2 (ambient atmosphere). Quality parameters of the roots were determined directly after harvest and after storage: CIE L*a*b* parameters, soluble solids, nitrate, total carotenoid and β-carotene content, and radical-scavenging activity (with the DPPH method). During storage of the carrots, soluble solids content showed a tendency to increase, while total carotenoid, β-carotene and nitrate contents tended to decrease. The results showed a significant positive influence of CA storage on the delay of quality degradation of carrots, compared with regular cold store conditions. In particular, storage under CA resulted in decreased negative root colour changes, decreased carotenoid losses and increased radical-scavenging activity of the purple-coloured cultivars. The best results were obtained after storage under a gas composition of 5% CO_2 + 10% O_2.

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INTRODUCTION

Carrot (*Daucus carota* L.) is an important vegetable crop, consumed all year round. Orange root carrot cultivars, which are widely grown in Europe, derive from eastern anthocyanin-containing types with purple or violet roots. Several cultivars with creamy-white, yellow, purple or violet roots have been developed by European breeders and introduced into horticultural practice in Europe [Rubatzky et al. 1999]. The high biological value of carrot relates mainly to carotenoid compounds and dietary fibre [Alasalvar et al. 2005]. The main carotenoids in carrot are α-carotene and β-carotene [Mayer-Miebach and Spiess 2003]. Carotenoid content is highly differentiated among carrot cultivars, and ranges from 4 to 25 mg $100 \cdot g^{-1}$ FW or even more [Rubatzky et al. 1999]. According to Skrede et al. [1997], high carotenoid content in carrots results in a more reddish and darker colour of the roots. Purple coloured carrots contain higher quantities of phenolics and exhibit higher antioxidant capacity [Alasalvar et al. 2001, Nicolle et al. 2004, Gajewski et al. 2007].

Storage conditions are among the main factors influencing the degradation of carrot root quality during the postharvest period [Seljasen 2001]. Mature carrot roots can be stored in regular cold stores for 4–6 months, depending on the cultivar and the initial quality of the roots. Recommended storage conditions are 0–1°C and 95–98% RH [Brecht 2003]. Purple-coloured carrots are not suitable for long-term storage, and their quality degrades even in cold store conditions [Alasalvar et al. 2005]. Changes in the chemical composition of carrots take place during the storage period. Koca and Karadeniz [2008] observed a decrease of phenolics in carrots during six months of storage. The anthocyanin content of purple cultivars can also decrease during the postharvest period, even very soon after harvest [Alasalvar et al. 2005]. As regards sugar content, an increase in hexoses and decrease in sucrose content was observed by Suojala [2000]. Several authors have reported that carotenoid content in carrot roots is little affected by storage [Kidmose et al. 2004, Koca and Karadeniz 2008]. Sometimes even an increase in carotenoid content is observed [Kopas-Lane and Warthesen 1995].

The results of experiments carried out with the use of controlled atmosphere (CA) for long-term storage of carrots are unclear. For the storage of carrots, some authors recommend CA variants such as 5% CO_2 + 10% O_2, 2% CO_2 + 5% O_2 or 5% CO_2 + 5% O_2 [Brecht 2003, Alasalvar et al. 2005]. According to Leshuk and Saltveit [1990], CA storage does not generally extend the storage life of carrots compared with ambient atmosphere storage, and storage under oxygen levels below 3% can even result in increased off-flavours and off-odours of the roots. However, Izumi et al. [1996] reported that CA storage decreased decay, weight loss and pH changes of carrot sticks and slices. Alasalvar et al. [2005] found that modified atmosphere packaging (90% N_2, 5% O_2, 5% CO_2) resulted in better sensory quality and extended shelf life for minimally processed purple carrots, but no difference was observed for orange carrots. Whole carrot roots stored under CA were found to suffer less spoilage and moisture loss than carrots kept in a regular cold store [Opoku et al. 2009]. Hansen and Rumpf [1974] found that in carrots stored under a CA of 6% CO_2 + + 3% O_3 losses of sugars were 55% lower than under normal atmosphere, and conversion of di-saccharides to mono-saccharides was largely inhibited, which contributed to improvement in the taste and smell of the roots. Similar results were reported by Gajewski et al. [2010]. Therefore, it seems that the possibility of using CA technology for the long-term storage of carrots should be investigated in more detail, particularly in relation to carrot cultivars of different root colours.

The objective of this study was to determine the influence of long-term storage of carrot cultivars differing in root colour, in CAs with different gas compositions, on certain quality parameters of the roots.

MATERIAL AND METHODS

Eight carrot cultivars with different root colours were used in the study: 'Perfekcja' – orange, cylindrical roots;

'Interceptor' – orange-red, elongated roots; 'Vita Longa' – orange, conical; 'Nebula' F_1 – orange, cylindrical; 'Purple Haze' F_1 – purple, with orange core; 'Deep Purple' F_1 – purple; 'Mello Yello' F_1 – yellow; 'White Satin' F_1 – creamy-white roots. Carrot roots were obtained from an experimental field of WULS-SGGW in Wilanów, Warsaw. The carrot plants were grown in an alluvial soil of pH 6.0–6.5, humus content 1.9–2.3% and underground water level 150–200 cm. Amounts of nutrients in the soil were maintained at levels of 180–200 mg $K \cdot dm^{-3}$, 60–80 mg $P \cdot dm^{-3}$, 120–140 mg $N \cdot dm^{-3}$. Half of the N dose was applied before sowing and the rest in mid-season. Carrot seeds were sown in mid-May, at a rate of 0.8–1.0 million·ha. Directly after harvest the carrot roots were stored for 6 months (until mid-April) in a cold store chamber at a temperature of 0–1°C and RH 98%. Four different atmospheric compositions were applied during storage: CA 5% CO_2 + 10% O_2; CA 2% CO_2 + 5% O_2; CA 5% CO_2 + 5% O_2; regular atmosphere (0% CO_2 + 21% O_2). Nitrogen accounted for the remaining part of the atmosphere.

The carrot roots were stored in airtight steel containers (each 1 m^3 in volume). The composition of the atmosphere was measured with a gas analyser and was automatically maintained at the set level with an accuracy of +/–0.5%. For the experiment, a complete CA storage system, enabling modification and control of atmospheric conditions, produced and assembled by COOLEX (Warsaw-Karczew, Poland), was used. For storage, the roots were packed into plastic crates with a capacity of 15 kg. A two-factor experiment was conducted in four replicates, with 15 kg of carrot roots in one replicate. The data presented are the means of values from two growing seasons.

Observations and analyses of the roots were performed directly after harvest and after the storage period (six months), on representative samples of the roots taken from each replicate. Colour parameters of carrot roots and juice were determined with a HunterLab XE spectrophotometer (HunterLab, USA), using the CIE L*a*b* scale, with 10°/D65 instrument setup. The measurements were taken from the cleaned surface of the root in the middle of its length. Soluble solids content was determined with a digital refractometer and expressed as °Brix. Carotenoid content was determined spectrophotometrically [PN-90/A-75101.12]. Deep frozen samples were ground with anhydrous sodium sulphate and extracted with hexane. Total carotenoid content was determined using a UV-1201V spectrophotometer (Shimadzu, Japan) with a wavelength of 450 nm. Next, β-carotene was separated by a column chromatography method and determined spectrophotometrically. Nitrate (NO_3) content in the roots was determined spectrophotometrically. Finely grated roots were extracted with acetic acid (10 g sample + 100 mL of 2% acetic acid + active carbon to eliminate colour). Filtrated extracts were injected into a FIAstar instrument (Foss Tecator, DK), and nitrate content was determined at a wavelength of 440 nm (www.Foss.dk). The antioxidant activity of the roots was determined according to Yen and Chen [1995], as the percentage of DPPH (2,2-diphenyl-1-picrylhydrazyl) free radical scavenging activity in methanol extract. Samples of carrots were ground and extracted for 30 min in methanol. Measurements were performed with a UV-1201V spectrophotometer (Shimadzu, Japan) after 10 min of reaction in 10% extracts, with wavelength 517 nm.

For the data analysis, one-way ANOVA was applied. Statgraphics Plus 4.1™ software was used for the analysis of variance, and Tukey's HSD test was used to show which values differ significantly at P = 0.05. The analysis was performed for each cultivar separately, due to the strongly differing characteristics of the cultivars.

RESULTS AND DISCUSSION

The influence of CA storage on the quality of carrot roots has to date not been clearly explained, particularly for different coloured types. Some authors are of the opinion that this storage method does not bring any benefit and makes carrots susceptible to increased CO_2 levels [Abdel-Rahman and Isenberg 1974, Suslow et al. 2002]. Other authors have pointed out that CA storage (2–6% O_2 + 3–4% CO_2) may decrease saccharose losses and other losses in carrots in storage [Weichmann and Ammerseder 1974]. In our study, CA storage was found to have an evident positive effect on the evaluated carrot quality traits. Root colour is an important quality indicator. The colour of carrots results from the presence of carotenoid compounds in the roots. In our study, the roots stored under CA conditions showed smaller changes in colour parameters compared with storage under ambient atmosphere (regular cold store). As regards the L^* colour parameter, which describes the lightness of the carrots, the roots stored in ambient atmosphere had significantly lower values after storage then before storage, which indicates more advanced darkening of the roots (Table 1). By contrast, carrots stored under CA conditions had an L^* value similar to the initial value, regardless of the gas composition. The influence of storage conditions on the a^* parameter (redness) was less definitive; however, most of the cultivars showed a decrease in this parameter in the case of ambient atmosphere storage, while the

TABLE 1. Parameter L^* values for carrots depending on gas composition in storage

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	41.1 b	41.0 b	41.2 b	41.2 b	40.3 a
Interceptor	42.0 b	41.5 b	42.4 b	41.4 b	40.2 a
Vita Longa	39.2 b	39.3 b	39.2 b	39.1 b	37.4 a
Nebula	38.8 c	37.6 b	37.2 b	37.5 b	36.7 a
Deep Purple	23.2 b	23.0 b	23.8 b	23.4 b	22.1 a
Purple Haze	27.8 a	27.7 a	27.3 a	27.6 a	27.6 a
Mello Yello	32.9 b	30.3 a	31.0 a	30.7 a	30.3 a
White Satin	32.1 b	31.8 b	31.4 b	31.6 b	30,6 a

Values for the cultivars differing in relation to gas compositions according to Tukey's HSD test at P = 0.05 are marked with different letters.

decrease was smaller or even insignificant after storage under CA, in the case of all gas compositions (Table 2). The same was observed in the case of the b* parameter (yellowness) – Table 3. Taking into account all three CIE colour parameters, it can be concluded that CA conditions reduced the colour changes resulting from the storage of carrots, compared with regular cold store conditions.

Carrots stored under CA conditions showed small differences in contents of soluble solids and nitrates compared with carrots stored under regular atmosphere. The studied CA variants showed no clear differences in their influence on soluble solids content in the roots (Table 4). Purple-coloured carrots had the highest soluble solids content, regardless of storage conditions. Weichmann and Ammerseder [1974] reported that storage of carrots under a CA with gas composition 2–6% O_2 + 3–4% CO_2 was beneficial in reducing saccharose loss and quality degradation due to growth of lateral roots and leaves. CA-stored carrots have been found to have a sweeter taste com-

TABLE 2. Parameter a^* values for carrots depending on gas composition in storage

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	14.38 c	13.49 b	13.27 b	13.32 b	12.17 a
Interceptor	20.92 c	19.53 b	19.28 b	19.29 b	18.32 a
Vita Longa	18.65 b	17.40 a	17.85 a	17.14 a	17.61 a
Nebula	14.35 b	14.10 b	14.34 b	14.78 b	12.32 a
Deep Purple	0.05 a	0.02 a	0.11 a	0.12 a	0.01 a
Purple Haze	3.21 b	3.01 b	3.35 b	3.20 b	2.29 a
Mello Yello	3.52 b	3.20 b	3.76 b	3.51 b	2.38 a
White Satin	1.48 a	1.39 a	1.12 a	1.30 a	0.77 a

Explanations as in Table 1.

TABLE 3. Parameter b^* values for carrots depending on gas composition in storage

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	22.2 c	20.5 b	20.1 b	20.8 b	19.9 a
Interceptor	25.2 c	23.3 b	23.4 b	23.5 b	21.5 a
Vita Longa	24.8 b	23.5 a	24.1 ab	23.9 a	23.2 a
Nebula	21.4 b	19.8 a	19.3 a	19.5 a	19.0 a
Deep Purple	0.6 b	0.2 a	0.3 a	0.3 a	0.1 a
Purple Haze	2.5 b	2.4 b	2.6 b	2.9 b	1.4 a
Mello Yello	17.3 c	15.8 b	15.6 b	16.3 b	14.9 a
White Satin	7.1 b	7.1 b	7.9 b	7.9 b	6.6 a

Explanations as in Table 1.

TABLE 4. Soluble solids content in carrots depending on gas composition in storage (°Bx)

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	9.9 a	9.3 a	10.7 b	9.8 a	9.6 a
Interceptor	9.4 a	9.1 a	9.7 b	9.5 ab	9.6 ab
Vita Longa	8.8 b	9.1 c	8.7 b	8.5 b	7.6 a
Nebula	8.4 b	7.5 a	7.8 a	7.5 a	7.6 a
Deep Purple	10.8 ab	11.0 b	10.4 a	11.4 c	10.7 a
Purple Haze	10.8 b	7.8 a	11.5 c	10.7 b	10.6 b
Mello Yello	9.1 b	9.9 c	7.9 a	9.4 bc	8.1 a
White Satin	8.1 b	8.9 c	7.4 a	8.0 b	8.3 b

Explanations as in Table 1.

pared with carrots stored under regular atmosphere [Gajewski et al. 2010].

Nitrates are undesirable components of carrots [Santamaria 2005]. In our study, nitrate (NO_3) content in the carrot roots exhibited a small downward tendency, regardless of storage conditions (Table 5). The influence of different CA variants on nitrate content was dependent on cultivar, but generally the lowest nitrate content was found for the composition 5% CO_2 + 5% O_2. 'White Satin', 'Deep Purple' and 'Purple Haze' carrots generally had the highest nitrate contents.

Carotenoid compounds are a significant bioactive component of carrots due to their pro-vitamin A activity and antioxidative action [Alasalvar et al. 2001, 2005]. The results showed that the gas composition of the atmosphere was not a significant factor for carotenoid changes, but generally total carotenoid content showed a tendency to decrease in the case of 'Purple Haze' (Table 6). A similar tendency was noted for the β-carotene

TABLE 5. Nitrate content in carrots depending on gas composition in storage (mg $NO_3 \cdot kg^{-1}$ FW)

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	235 c	108 a	133 ab	179 b	166 b
Interceptor	339 c	168 b	159 b	109 a	187 b
Vita Longa	187 b	175 b	215 c	129 a	177 b
Nebula	241 b	289 b	136 a	167 a	143 a
Deep Purple	318 b	361 b	195 a	140 a	205 a
Purple Haze	264 b	214 a	277 b	181 a	213 a
Mello Yello	244 b	154 a	251 b	153 a	228 b
White Satin	286 ab	257 ab	197 a	378 b	396 b

Explanations as in Table 1.

TABLE 6. Total carotenoid content in carrots depending on gas composition in storage (mg 100·g^{-1} FW)

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	6.0 a	6.6 b	5.7 a	6.0 a	6.9 b
Interceptor	6.6 a	7.9 b	6.1 a	6.9 ab	8.0 c
Vita Longa	7.2 c	8.0 d	7.3 c	6.2 b	5.2 a
Nebula	7.0 a	6.8 a	7.5 b	7.1 a	7.6 b
Deep Purple	0.8 a	0.8 a	0.8 a	0.8 a	1.1 b
Purple Haze	12.6 c	11.8 c	10.4 b	10.5 b	8.6 a
Mello Yello	1.5 a	1.3 a	2.0 b	0.9 a	1.4 a
White Satin	0.1 a	0.0 a	0.2 a	0.1 a	0.2 a

Explanations as in Table 1.

TABLE 7. β-carotene content in carrots depending on gas composition in storage (mg 100·g^{-1} FW)

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	3.2 b	3.2 b	2.3 a	3.3 b	3.0 b
Interceptor	3.8 b	3.0 a	3.1 a	3.8 b	3.7 b
Vita Longa	3.2 b	3.7 b	3.1 b	3.6 b	2.4 a
Nebula	3.0 a	3.5 a	3.2 a	2.9 a	3.1 a
Deep Purple	0.1 a	0.1 a	0.0 a	0.1 a	0.3 a
Purple Haze	5.3 b	5.2 b	4.9 b	5.0 b	3.8 a
Mello Yello	1.0 a	0.8 a	0.9 a	0.7 a	0.5 a
White Satin	0.2 a	0.1 a	0.1 a	0.0 a	0.0 a

Explanations as in Table 1.

content of the roots (Table 7). The influence of storage conditions on carotenoid compounds during long-term storage of carrots is not clear [Lee 1986, Kopas-Lane and Warthesen 1995]. According to Alasalvar et al. [2005], storage of carrots under CA conditions, especially with a gas composition of 95% O_2 + 5% CO_2, can decrease carotenoid content in the roots. The author observed faster degradation of carotenoid compounds in purple-coloured carrots under this gas composition compared with regular atmospheric conditions. Brecht [2003] reported an increase in carotenoid content in stored carrots.

The radical-scavenging activity of carrot extracts, measured with the DPPH method, decreased after storage in the case of ambient atmospheric conditions (Table 8). These carrots tended to have lower activity than CA-stored carrots. On average, the highest activity was found for the purple carrots ‘Deep Pur-

TABLE 8. Radical-scavenging activity of carrot extracts depending on gas composition (% DPPH)

Cultivar	Directly after harvest	Gas composition of atmosphere (% CO_2 + % O_2)			
		5 + 10	2 + 5	5 + 5	ambient
Perfekcja	16.3 b	15.5 b	11.9 a	18.9 c	12.4 a
Interceptor	21.2 a	25.2 b	25.3 b	23.7 b	20.5 a
Vita Longa	27.6 b	20.0 a	22.4 ab	23.1 ab	26.8 b
Nebula	20.2 ab	22.8 bc	24.5 c	18.3 a	21.5 b
Deep Purple	60.0 b	68.6 c	66.5 c	58.5 b	45.3 a
Purple Haze	58.6 ab	71.6 c	67.5 bc	63.5 b	52.5 a
Mello Yello	14.5 c	15.8 c	14.7 c	10.0 a	12.3 b
White Satin	5.9 a	4.2 a	3.9 a	5.0 a	4.4 a

Explanations as in Table 1.

ple' and 'Purple Haze', and the lowest for the white-coloured carrot 'White Satin'. Storage of carrots under CA conditions positively influenced the radical-scavenging activity of purple-coloured carrots. This is in agreement with the results of Alasalvar et al. [2005], who observed that a modified atmosphere did not influence the antioxidant activity of orange-coloured carrots, but positively affected the activity of purple-coloured ones.

CONCLUSIONS

The study of the storage of carrots, including cultivars with other than orange-coloured roots, under different atmospheric gas compositions has shown CA storage to have a positive effect on the quality of the roots compared with regular cold store conditions. It was found that CA conditions reduced changes in the roots' CIE colour parameters and carotenoid degradation. The antioxidant activity of purple-coloured cultivars increased after storage under CA. The best storage results were obtained in the case of an atmospheric gas composition of 5% CO_2 + + 10% O_2. The purple-coloured cultivars 'Deep Purple' and 'Purple Haze' exhibited higher antioxidant activity than orange-coloured cultivars.

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Streszczenie: *Wpływ przechowywania w chłodni z kontrolowaną atmosferą na wybrane cechy jakościowe odmian marchwi o różnych kolorach.* Odmiany marchwi o różnych kolorach korzeni cieszą się coraz większym zainteresowaniem odbiorców w Europie. Większa część zbiorów marchwi wymaga przechowywania przez okres kilku miesięcy, co jest przyczyną utraty jakości plonów. Celem badań było określenie wpływu długotrwałego przechowywania marchwi w warunkach chłodni ze zróżnicowanym składem atmosfery (KA) na wybrane cechy jakościowe odmian o różnych kolorach. Marchew o korzeniach pomarańczowych ('Nebula' F_1), fioletowo-pomarańczowych ('Purple Haze'), fioletowych ('Deep Purple' F_1), żółtych ('Mello Yello') oraz białokremowych ('White Satin' F_1) była przechowywana przez sześć miesięcy w temperaturze 0–1°C i wilgotności względnej 95%, w warunkach atmosfery o składach gazowych: 5% CO_2 + 10% O_2, 2% CO_2 + 5% O_2, 5% CO_2 + 5% O_2 lub 0% CO_2 + 21% O_2 (skład normalny). Bezpośrednio po zbiorze i przechowaniu określano następujące cechy korzeni: parametry barwy w systemie CIE L*a*b*, zawartość ekstraktu, azotanów(V), karotenoidów ogółem i β-karotenu oraz zdolność wyłapywania wolnych rodników ekstraktów metanolowych z korzeni (metodą DPPH). W wyniku przechowywania zawartość ekstraktu, karotenoidów ogółem, β-karotenu i azotanów(V) wykazywała tendencję spadkową, zmiany te jednak zależały od odmiany. Wyniki wskazują na pozytywny wpływ przechowywania w warunkach KA na ograniczenie tempa procesów degradacji jakości w porównaniu do przechowywania w warunkach chłodni z atmosferą normalną. Warunki KA w szczególności wpłynęły na ograniczenie negatywnych zmian barwy korzeni, ograniczenie strat ekstraktu i karotenoidów oraz na wzrost aktywności antyrodnikowej odmian marchwi o fioletowej barwie. Najlepsze wyniki uzyskano w przypadku przechowywania marchwi w warunkach składu atmosfery 5% CO_2 + + 10% O_2.