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# Sensory Quality of Orange, Purple and Yellow Carrots Stored under Controlled Atmosphere

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**Abstract**

The influence of long-term storage of carrot (*Daucus carota* L.) roots under normal and controlled atmosphere (CA) on their sensory quality and soluble solids content was investigated. Carrot cultivars of orange ('Nebula'), purple-orange ('Purple Haze') and yellow ('Mello Yello') colour of the roots were stored for 6 months at 0-1°C, under controlled atmosphere (CA) of gas composition 5% $CO_2$+10% $O_2$, 2% $CO_2$+5% $O_2$, 5% $CO_2$+5% $O_2$ and at normal atmosphere. Sensory quality was evaluated with quantitative descriptive analysis method. Roots of 'Nebula' showed the best overall quality under normal atmosphere, although CA resulted in higher firmness and crunchiness. Roots of 'Purple Haze' showed the best quality under 5% $CO_2$+5% $O_2$ or 5% $CO_2$+10% $O_2$. Storage in these CA variants resulted in higher sweetness, juiciness, crunchiness and firmness. Roots of 'Mello Yello' showed the smallest differences in quality under CA variants. Storage of carrots in CA did not result in off-flavour or off-odour. CA-stored roots showed higher soluble solids content.

***Keywords:*** carrot cultivars, storage conditions, sensory quality, quantitative descriptive analysis, soluble solids

## Introduction

Carrot (*Daucus carota* L.) is an important vegetable crop worldwide, consumed by humans during the whole-year period in different forms. According to Mazza (1989), the most important quality attributes of carrot roots delivered for fresh market are: root size, shape, uniformity, colour, texture and internal quality aspects (sensory quality and biological value). Carrot cultivars of orange coloured root, which are widely grown in Europe, derive from Eastern, anthocyanins-containing types of purple or violet root (Banga, 1984; Rubatzky *et al.*, 1999). Recently, several cultivars of creamy-white, yellow, purple or violet root have been bred by European breeders and then introduced to horticultural practice.

Most of the produce is stored after harvest for several months before consumption. Storage conditions are among the main factors influencing degradation of carrot roots quality during postharvest period (Seljasen, 2001). Mature carrot roots can be stored in regular cold stores for 4-6 months, depending on the cultivar and initial quality of the roots. The most recommended storage conditions for carrots are: temperature of 0-1°C and 95-98% RH (Stoll and Weichmann, 1987; Suslow *et al.*, 1998; Brecht, 2003). Results of experiments carried out with controlled atmosphere (CA) application for long-term storage of carrots are unclear. According to Leshuk and Saltweit (1990), CA does not generally extend storage-life of carrots and storage of carrots under oxygen level below 3% can result in increased off-flavors and off-odors. Also Suslow *et al.* (1998) suggested that positive effect of CA conditions on carrots quality was not reliable, so this method of storage could not be widely recommended. However, in some countries the possibility of CA storage for carrots is still under study. Especially, the controlled atmosphere for minimally processed carrots proved to be beneficial. Izumi *et al.* (1996) reported that CA decreased decay, weight loss and pH changes of carrot sticks and slices. Alasalvar *et al.* (2005) found that MAP (modified atmosphere packaging) treatment (90% $N_2$, 5% $O_2$, and 5% $CO_2$) gave better sensory quality and extended the shelf life for minimally processed purple carrots, but no difference was observed for orange carrots. According to the results obtained by Opoku *et al.* (2009) in a study carried out in Canada, the whole carrot roots stored under CA conditions had less spoilage and moisture loss compared to the carrots kept in a regular cold store. Hansen and Rumpf (1974) found that in carrots stored under CA of 6% $CO_2$+3% $O_3$ losses of sugars were 55% lower than under normal atmosphere conditions and conversion of disaccharides to monosaccharides largely inhibited, which contributed to better taste and smell of the roots. Therefore, it seems that the possibility of CA technology implementation for long-term storage of carrots should be investigated more detailed, particularly in relation to new carrot cultivars of various root colour.

Sensory evaluation of vegetables brings valuable information on their quality characteristics. Sensory traits are usually the main factor determining consumer's satisfaction (Abbott, 1999). The quantitative descriptive analysis

(QDA) method is applied for detailed description of sensory quality of food. In this method an assumption is made that the sensory quality is a complex of many descriptors, which can be individually estimated by a consumer (Meilgaard *et al.*, 1999). For the unification of sensory methods international standards of the evaluation were approved (Anonymous, 1996; 1999). In investigations of sensory quality of carrots with QDA method different sets of attributes were used (Martens *et al*., 1983; 1985). The descriptors used in some studies were: smell typical of carrot, terpene smell, flavour typical of carrot, terpene flavour, sweet and bitter taste, as well as burning aftertaste (Seljasen *et al.*, 2002; Kreutzmann *et al.*, 2008a; 2008b). Most sensory descriptors of carrots are influenced by a cultivar, as well as growing conditions (Simon *et al.*, 1980a; Varming *et al.*, 2004; Da Silva *et al*., 2007). Studies on carrot sensory quality, presented in literature, are very fragmentary, and their results are sometimes contradictory. Haglund *et al.* (1999) found that conventionally grown carrots had a sweeter taste and were crunchier than ecologically grown ones. As sensory attributes, hardness, crunchiness, juiciness, sweetness, bitterness, carrot taste and aftertaste were used in the study. There are some reports on the relationship between sensory quality and physical or chemical characteristics of vegetables (Fillion and Kilcast, 2002; Gajewski, 2003; Gajewski and Arasimowicz, 2004), but is few data on the influence of storage conditions on sensory characteristics of carrots of different types, particularly other than orange ones. Quite strong correlation between flavour compounds content and sensory quality of the roots was reported by Varming *at al.* (2004). However, Martens *et al*. (1983) found that only 23% of the variation in sensory quality could be predicted on the basis of chemical composition analysis of carrots. According to these authors, consumer's liking of carrots is generally correlated to perceived sweetness. However, Rosenfeld *et al.* (1997) and Rosenfeld and Lea (1998) reported that sugars content in the roots was not a reliable indicator of carrots sweetness. The opposite opinion expressed Simon *et al.* (1982) and Howard *et al.* (1995). Simon *et al.* (1980a) emphasized the significance of sugars and volatile terpenes in generating impression of the flavour typical of raw carrots. According to Simon (1985) also terpenes affect carrot flavour, but mainly by accentuating the sweet taste.

Kreutzmann *et al.* (2008a, 2008b) reported that sensory quality of carrots was related mainly to chlorogenic acid, sucrose, 6-metoxymellein, falcarindiol and falcarinol content in the roots. They believe, however, that a noticeable part of the variation of the quality (about 40%) is not related to the chemical composition of the roots. Alabran and Mabrouk (1973) found that non-volatile compounds (sugars and amino acids) were the main chemical compounds responsible for flavour typical of fresh carrots, but volatile compounds had smaller impact on the sensory quality. Alasalvar *et al.* (2001) reported that sensory quality of carrots was related mainly to non-volatile bitter compounds and sugars, and these compounds could also influence significantly sensory perception of volatiles. Rosenfeld *et al.* (1997), Kreutzmann *et al.* (2008b) and Surles *et al.* (2005) underlined the significance of the genotype in sensory profile of carrot. The authors suggest that different genotypes of carrot, differing in root colour (orange, red, yellow and white) show great variations in sensory quality. According to Alasalvar *et al*. (2001), roots of purple coloured carrots got the highest scores for sensory quality, but Surles *et al.* (2005) found that roots of orange or creamy coloured carrots had better sensory quality than yellow, red or purple coloured ones. The negative correlation between sucrose content in the roots and foreign taste intensity indicates that the sugars have a masking effect on foreign taste impression.

During storage period a declining of overall sensory quality score, as well as of hedonic score for liking is often observed for carrots, which is related to several changes in sensory quality descriptors (Fenwick *et al.*, 1990; Gajewski and Dąbrowska, 2007). Evers (1989) reported that storage of carrot roots negatively influenced flavour and texture attributes. According to Seljasen *et al.* (2001, 2002), factors influencing sensory quality degradation of carrots in retail are: mechanical stress, ethylene action, increasing temperature and anaerobic respiration in the absence of oxygen. Mechanical injuries of carrot roots result in increasing ethylene production, which influences sugars utilization in the respiration process and consequently decreasing sweet taste intensity (Mempel and Geyer, 1999). Bitter taste is a negative quality attribute of carrots, adversely affecting consumer's attitude. It can result from stresses during vegetation period, harvest or storage (Kuusi and Virtainen, 1979; Simon *et al.*, 1980b; Talcott *et al.*, 2001; Kreutzmann *et al*., 2008a). It is caused by accumulation of isocoumarin 6-methoxymellein (Seljasen *et al.*, 2001). Presence of ethylene in the atmosphere stimulates 6-methoxymellein synthesis in the roots (Seljasen *et al*., 2002). In turn, oxygen deficiency in the atmosphere during storage of carrots increases ethanol flavour intensity due to ethanol synthesis in the roots tissue, which, however, does not affect 6-metoxymelleine synthesis. Carbon dioxide in high concentration decreases synthesis of 6-metoxymelleine, even in presence of ethylene. Bitter compounds synthesis is stimulated also by high temperature of storage (above 15°C) (Lafuente *et al*., 1989). Bitter taste can also result from an infection by certain pathogens, mainly by fungi from *Fusarium* and *Alternaria* genus (Lafuente *et al.*, 1989; Czepa and Hofmann, 2003).

The objective of the study was to determine the influence of long-term storage under various CA conditions on sensory quality of carrot roots of different colour. Soluble solids content in the roots was also determined as the indices of the roots sweetness.

**Material and methods**

*Material*

The experiment was carried out in Warsaw University of Life Sciences in the storage season 2008-2009. Carrots were grown in the experimental field of the University in an alluvial soil of pH 6.0-6.5, of humus content 1.9-2.3%, and underground water level of 150-200 cm. Fertilizing of the field was applied according to the results of the soil analysis, and the amount of nutrients in the soil was kept at the levels of 180-200 mg K $dm^{-3}$, 60-80 mg P $dm^{-3}$, 120-140 mg N $dm^{-3}$. Carrot seeds were sown to the standard ridges in mid-May and harvested in mid-October. Three carrot cultivars of different colour of storage root were used in the study-'Nebula' $F_1$ ('Royal Sluis'), 'Purple Haze' $F_1$ and 'Mello Yello' $F_1$ ('Bejo Zaden'). 'Nebula' is a cultivar in 'Nantes' type, of orange coloured, cylindrical root; 'Purple Haze'-a cultivar of purple coloured cortex and orange core of the root and 'Mello Yello'-a cultivar of yellow coloured root.

After harvest, the carrot roots were stored for 6 months (till mid-April) in a cold store at the temperature of 0-1°C and RH of 97%. Four different compositions of atmosphere were applied during storage: (1) CA 5% $CO_2$+10% $O_2$, (2) CA 2% $CO_2$+5% $O_2$, (3) CA 5%$CO_2$+5% $O_2$, (4) normal atmosphere, i.e. 0% $CO_2$+21% $O_2$. Nitrogen accounted for the remainder part of atmosphere.

The CA variants were chosen according to previous reports found in literature and own preliminary experiments performed with carrots. The carrot roots were stored in airtight steel containers (of 1 $m^3$ volume each). Composition of the atmosphere was measured with a gas analyzer and was automatically kept on settled level with the accuracy of ±0.5%. For the experiment, CA complete storage system, enabling modification and control of atmospheric conditions, made and assembled by COOLEX (Warsaw-Karczew, Poland), was used. For the storage, the roots were packed into plastic crates, capacity of 15 kg. The experiment was established as the two-factor one, in four replicates. There were 15 kg of carrot roots in one replicate. Sensory analysis of the roots was performed directly after harvest and after the storage period, on representative samples of the roots, as it is described below.

*Analytical methods*

Sensory analysis was performed in sensory laboratory of the University, equipped according to the ISO standard (Anonymous, 1999; 2004). The panel, consisting of 12 experts, previously selected and trained (Anonymous, 1996), carried out the evaluation, using the quantitative descriptive analysis (QDA). At the first part of QDA procedure 'brainstorming' sessions were run to select sensory attributes for the carrots. Assessors received samples of carrots, varying in sensory properties, and generated a set of 13 sensory quality attributes (Tab. 1) which included basic odour and taste attributes as well as attributes specific to carrot. Also overall impression for sensory quality was scored. The set of quality attributes was similar to the one used in our other study on carrots (Gajewski and Dąbrowska, 2007). The sensory analysis was performed in separate booths, equipped with computers for data collection. Every assessor was given randomized samples of the carrots. For the assessment, the roots were cut into slices of 1 cm thick and put into small plastic containers, covered by lids. The assessments were marked on non-structural lines accompanied by anchoring points. The results were converted to numerical values (from 0 to 10). The analysis was performed during two independent sessions. For coding the samples and for initial processing of the data, Analsens™ software was used.

Semi-consumer's hedonic test for overall liking of carrots was also performed. For the test the non-structural scale was used, with anchoring points: 'I do not like it'-'I like it very much'.

Soluble solids content in carrot roots was determined with digital Abbe's refractometer and expressed in Brix scale (°Bx).

Tab. 1. Sensory quality attributes used in sensory analysis of carrot roots

| | Attributes | Definition | Anchoring points |
|---|---|---|---|
| 1 | Odour of raw carrot | Odour characteristic to raw carrot roots | Not detectable-very intensive |
| 2 | Sweet odour | Pleasant, sweet aroma | Not detectable-very intensive |
| 3 | Off-odour | Foreign odour, unusual for carrot | Not detectable-very intensive |
| 4 | Colour of outer part | Evaluation of flesh brightness | Bright -dark colour |
| 5 | Colour of inner part | Evaluation of flesh brightness | Bright -dark colour |
| 6 | Firmness | Force needed to chew the roots | Firm - soft |
| 7 | Crunchiness | Amount of liquid released during chewing | Not juicy-very juicy |
| 8 | Juiciness | Mouthfeel of roots crunchiness | Not crunchy-very crunchy |
| 9 | Flavour of raw carrot | Characteristic flavour of fresh carrot | Not detectable-very intensive |
| 10 | Sweet taste | Basic taste | Not detectable-very intensive |
| 11 | Sour taste | Basic taste | Not detectable-very intensive |
| 12 | Bitter taste | Basic taste | Not detectable-very intensive |
| 13 | Off-flavour | Foreign flavour, unusual for carrots | Not detectable-very intensive |
| 14 | Overall quality | Score for general sensory quality | Low-high quality |

*Statistical analysis*

The data obtained were statistically evaluated with ANOVA (StatgraphicsPlus™, Statpoint Technologies Inc., Warrenton, Virginia, USA). The significance of differences between the means was determined with Tukey HSD (honesty significance test) test, at significance level $P<0.05$. The least significant differences (LSD) were calculated and given for significance level $P<0.05$.

**Results and discussion**

For the evaluation of sensory characteristics of carrots with the QDA method three different types of carrots were chosen-orange, typical carrot, purple carrot and yellow carrot. In Europe the growing popularity of other types than orange carrots is observed, so their suitability for long-term storage with modern CA technology needs explanation. There are few reports on sensory characteristics of carrot as affected by CA storage; therefore discussion of the results must be limited. As it can be seen in Tab. 2, 3 and 4, the scores for sensory attributes for the cultivars were differentiated, which indicates that the cultivars varied in respect of sensory quality. In the case of freshly harvested roots the highest score for overall sensory quality (7.24 points in the scale of 0-10) got roots of 'Nebula', and the lowest roots of 'Purple Haze (6.79 points). The results are slightly different from the data reported by Alasalvar *et al.* (2001), who found that purple carrots were rated higher in sensory evaluation test than orange ones.

The results of QDA show that the influence of storage on sensory quality of carrots was differentiated among cultivars and storage conditions (gas composition of atmosphere) as well. Quality of carrots stored under different atmosphere compositions is compared here with the quality of freshly harvested roots. In the case of orange coloured 'Nebula' carrot, storage under CA 5% $CO_2$+10% $O_2$ resulted in decreasing of 'raw carrot odour' intensity of the roots, as well as sweet odour intensity compared with freshly harvested roots (Tab. 2). Texture of the roots changed in a high degree, as well. Namely, firmness, crunchiness and juiciness of the roots decreased significantly. Flavour of raw carrot' and sweet taste intensity for the roots also decreased. However, scores for colour intensity of the roots remained unchanged. As a result of the above changes, overall quality impression score for the carrots was lower after the storage period than immediately after harvest. Carrots stored under CA 2% $CO_2$+5% $O_2$ showed similar tendencies for quality changes, except sweet taste intensity, which changed in a less amount. Storage under CA 5% $CO_2$+5% $O_2$ resulted in greater changes in 'odour of raw carrot' intensity, but the changes in other attributes were smaller in that case than for carrots stored in the other CA variants. In particular, 'flavour of raw carrot' remained unchanged. What is important, storage in all CA variants did not cause increasing of off-odour, which is uncharacteristic of raw carrots. Storage under normal atmosphere conditions (i.e. in the regular cold store) resulted in small changes in odour attributes, but also in significant decreasing of the roots firmness and crunchiness, comparable with the changes observed for the CA stored samples. Changes in flavour attributes were smaller than in the CA stored carrots, however, especially in the case of 'flavour of raw carrot' attribute. Overall quality score for the stored carrots was significantly lower than for the freshly harvested ones, but slightly higher than for CA stored samples.

In the case of purple coloured 'Purple Haze' carrots, storage under CA 5% $CO_2$+10% $O_2$ resulted in small changes in odour attributes and texture attributes, only the juiciness of roots increased in a noticeable degree compared with freshly harvested roots (Tab. 3). Sweet taste

Tab. 2. Scores for sensory quality attributes for freshly harvested and stored roots of cv. 'Nebula' in relation to atmosphere composition (scale 0-10)

| Sensory quality attributes | Freshly harvested | After storage at following atmosphere compositions | | | |
|---|---|---|---|---|---|
| | | 5% $CO_2$+10% $O_2$ | 2% $CO_2$+5% $O_2$ | 5% $CO_2$+5% $O_2$ | Normal atmosphere |
| Odour of raw carrot | $5.44^{d}$ | $4.68^{b}$ | $4.83^{b}$ | $3.76^{a}$ | $5.17^{c}$ |
| Sweet odour | $3.21^{b}$ | $2.68^{a}$ | $2.57^{a}$ | $2.39^{a}$ | $2.98^{b}$ |
| Off-odour | $0.00^{a}$ | $0.04^{a}$ | $0.19^{a}$ | $0.00^{a}$ | $0.13^{a}$ |
| Colour of inner part of roots | $4.74^{a}$ | $4.72^{a}$ | $4.49^{a}$ | $4.56^{a}$ | $4.70^{a}$ |
| Colour of inner part of roots | $4.98^{b}$ | $5.02^{b}$ | $5.06^{b}$ | $4.41^{a}$ | $4.92^{b}$ |
| Flesh firmness | $7.31^{c}$ | $6.87^{b}$ | $6.29^{a}$ | $6.73^{b}$ | $6.63^{b}$ |
| Flesh crunchiness | $7.37^{c}$ | $6.69^{b}$ | $6.08^{a}$ | $6.20^{a}$ | $6.01^{a}$ |
| Flesh juiciness | $5.51^{b}$ | $4.71^{a}$ | $4.81^{a}$ | $4.71^{a}$ | $5.23^{b}$ |
| Flavour of raw carrot | $6.27^{b}$ | $5.62^{a}$ | $5.80^{a}$ | $5.89^{ab}$ | $6.11^{b}$ |
| Sweet taste | $3.93^{b}$ | $2.60^{a}$ | $3.60^{a}$ | $3.55^{a}$ | $3.50^{a}$ |
| Sour taste | $0.26^{a}$ | $0.43^{b}$ | $0.61^{b}$ | $0.56^{b}$ | $0.28^{a}$ |
| Bitter taste | $0.95^{a}$ | $0.86^{a}$ | $0.69^{a}$ | $0.89^{a}$ | $1.09^{a}$ |
| Off-flavour | $0.00^{a}$ | $0.07^{a}$ | $0.07^{a}$ | $0.08^{a}$ | $0.00^{a}$ |
| Overall sensory quality | $7.24^{c}$ | $6.17^{a}$ | $6.35^{ab}$ | $6.26^{a}$ | $6.59^{b}$ |

Note: values in rows which differ according to Tukey's HSD test are marked with different letters

Tab. 3. Scores for sensory quality attributes for freshly harvested and stored roots of cv. 'Purple Haze' in relation to atmosphere composition (scale 0-10)

| Sensory quality attributes | Freshly harvested | After storage at following atmosphere compositions | | | |
|---|---|---|---|---|---|
| | | 5% $CO_2$+10% $O_2$ | 2% $CO_2$+5% $O_2$ | 5% $CO_2$+5% $O_2$ | Normal atmosphere |
| Odour of raw carrot | 4.65$^{ab}$ | 4.20$^{a}$ | 4.85$^{b}$ | 5.01$^{bc}$ | 5.28$^{c}$ |
| Sweet odour | 2.74$^{a}$ | 2.52$^{a}$ | 3.50$^{b}$ | 3.13$^{b}$ | 3.45$^{b}$ |
| Off-odour | 0.15$^{a}$ | 0.07$^{a}$ | 0.28$^{a}$ | 0.03$^{a}$ | 0.13$^{a}$ |
| Colour of inner part of roots | 8.43$^{ab}$ | 9.07$^{b}$ | 8.09$^{a}$ | 8.49$^{ab}$ | 9.02$^{b}$ |
| Colour of inner part of roots | 5.14$^{a}$ | 5.52$^{a}$ | 5.18$^{a}$ | 5.15$^{a}$ | 5.46$^{a}$ |
| Flesh firmness | 7.76$^{b}$ | 7.77$^{b}$ | 7.37$^{a}$ | 7.90$^{b}$ | 7.23$^{a}$ |
| Flesh crunchiness | 7.32$^{b}$ | 7.15$^{b}$ | 5.96$^{a}$ | 7.84$^{c}$ | 7.05$^{b}$ |
| Flesh juiciness | 4.38$^{a}$ | 4.97$^{ab}$ | 4.52$^{a}$ | 5.50$^{b}$ | 5.18$^{b}$ |
| Flavour of raw carrot | 5.74$^{a}$ | 5.90$^{ab}$ | 5.79$^{a}$ | 6.21$^{b}$ | 5.42$^{a}$ |
| Sweet taste | 4.06$^{a}$ | 5.40$^{b}$ | 4.16$^{a}$ | 4.78$^{ab}$ | 4.52$^{ab}$ |
| Sour taste | 0.22a | 0.35a | 0.52b | 0.45$^{b}$ | 0.69$^{b}$ |
| Bitter taste | 1.03$^{b}$ | 0.19$^{a}$ | 0.68$^{ab}$ | 0.39a | 0.65ab |
| Off-flavour | 0.06$^{a}$ | 0.00$^{a}$ | 0.24$^{a}$ | 0.04$^{a}$ | 0.10$^{a}$ |
| Overall sensory quality | 6.79$^{ab}$ | 7.50$^{b}$ | 6.26$^{a}$ | 7.60$^{b}$ | 7.04$^{b}$ |

Note: values in rows which differ according to Tukey's HSD test are marked with different letters

intensity increased significantly after storage under this CA conditions, but it did not affect overall quality score. Storage of the carrots under CA 2% $CO_2$+5% $O_2$ showed significant changes in quality in respect of firmness and crunchiness attributes only. Other attributes, including sweet odour and flavour, remained unchanged. Overall quality score showed a tendency to declining as an effect of storage. The changes of quality under CA 5% $CO_2$+5% $O_2$ concerned mainly the crunchiness and juiciness of the roots, which increased to some extent, but 'flavour of raw carrot' and sweet taste also increased in a noticeable degree. The changes observed for carrots stored under normal atmosphere were very small, and more noticeable in the case of 'odour of raw carrot' and flesh juiciness, which increased a little after the storage period. It was found that sour taste intensity increase a little.

Results of sensory evaluation of the roots of 'Mello Yello' carrots stored under CA 5% $CO_2$ + 10% $O_2$ showed only small changes in respect of colour of inner part of the root (decreasing of the colour intensity), increasing in root firmness and decreasing in root crunchiness (Tab. 4). Overall quality score decreased significantly. Generally, similar tendencies were found for firmness changes of the roots stored in CA 2% $CO_2$ + 5% $O_2$, however in that case 'flavour of raw carrot' and sweet taste were rated slightly higher for the stored roots than for the freshly harvested ones. Overall sensory quality was rated at the same level as for the freshly harvested roots. Storage of carrot roots at

Tab. 4. Scores for sensory quality attributes for freshly harvested and stored roots of cv. 'Mello Yello' in relation to atmosphere composition (scale 0-10)

| Sensory quality attributes | Freshly harvested | After storage at following atmosphere compositions | | | |
|---|---|---|---|---|---|
| | | 5% $CO_2$+10% $O_2$ | 2% $CO_2$+5% $O_2$ | 5% $CO_2$+5% $O_2$ | Normal atmosphere |
| Odour of raw carrot | 4.35$^{ab}$ | 4.39$^{ab}$ | 4.17$^{a}$ | 3.95$^{a}$ | 5.02$^{b}$ |
| Sweet odour | 2.42$^{a}$ | 2.80$^{a}$ | 2.58$^{a}$ | 2.34$^{a}$ | 2.86$^{a}$ |
| Off-odour | 0.25$^{b}$ | 0.10$^{a}$ | 0.00$^{a}$ | 0.00$^{a}$ | 0.04$^{a}$ |
| Colour of inner part of roots | 1.42$^{b}$ | 0.97$^{a}$ | 1.13$^{a}$ | 1.02$^{a}$ | 0.98$^{a}$ |
| Colour of inner part of roots | 1.78$^{a}$ | 1.43$^{a}$ | 1.44a | 1.47$^{a}$ | 1.46$^{a}$ |
| Flesh firmness | 7.62$^{a}$ | 8.49$^{b}$ | 8.49$^{b}$ | 8.71$^{b}$ | 8.58$^{b}$ |
| Flesh crunchiness | 8.03$^{ab}$ | 7.54$^{a}$ | 8.31$^{b}$ | 8.46$^{b}$ | 8.31$^{b}$ |
| Flesh juiciness | 5.38$^{a}$ | 5.38$^{a}$ | 5.45$^{a}$ | 5.64$^{a}$ | 5.61$^{a}$ |
| Flavour of raw carrot | 5.21$^{a}$ | 5.61$^{a}$ | 6.04$^{b}$ | 6.01$^{b}$ | 5.76$^{ab}$ |
| Sweet taste | 3.45$^{a}$ | 3.62$^{a}$ | 4.31$^{b}$ | 4.13$^{b}$ | 3.62$^{a}$ |
| Sour taste | 0.26$^{a}$ | 0.63$^{b}$ | 0.38$^{a}$ | 0.58$^{b}$ | 0.40$^{ab}$ |
| Bitter taste | 1.21$^{ab}$ | 1.91$^{b}$ | 0.66$^{a}$ | 0.95$^{a}$ | 1.81$^{b}$ |
| Off-flavour | 0.26$^{a}$ | 0.18$^{a}$ | 0.12$^{a}$ | 0.00$^{a}$ | 0.09$^{a}$ |
| Overall sensory quality | 7.05$^{b}$ | 6.44$^{a}$ | 7.33$^{b}$ | 7.34$^{b}$ | 6.47$^{a}$ |

Note: values in rows which differ according to Tukey's HSD test are marked with different letters

CA 5% $CO_2$+5% $O_2$ resulted in a tendency to decrease of 'odour of raw carrot', but to increase of root firmness and crunchiness compared with the freshly harvested roots. 'Flavour of raw carrot' and sweet taste intensity increased, similarly as in the case of storage in CA 2% $CO_2$+5% $O_2$ composition. Changes of sensory quality of the carrots stored under normal atmosphere conditions were to some extend similar as these for CA conditions, but overall quality score decreased significantly.

Generally, the roots of orange coloured 'Nebula' carrot showed the highest overall sensory quality after storage under the normal atmosphere conditions, although the CA storage resulted in a higher firmness and crunchiness of the roots. Different relationship was observed in the case of purple coloured `Purple Haze` carrot, which showed the best overall quality after storage under CA 5% $CO_2$+5% $O_2$ or 5% $CO_2$+10%$O_2$. Storage in these CA variants resulted mainly in more intensive sweet taste, higher juiciness, crunchiness and firmness of the roots than under other storage conditions. The positive effect of CA 5% $CO_2$+5% $O_2$ on quality of minimally processed purple carrots stored with MAP technology was reported by Alasalvar *et al.* (2005), so our study confirmed previous report, but in this case in relation to unprocessed roots. The yellow coloured roots of 'Mello Yello` showed the smallest reaction on storage conditions and their overall quality was rated similarly in the case of all storage variants. It seems important that storage in all CA gas compositions, as well as under the normal atmosphere did not cause any significant increase of off-flavour of off-odour in the roots.

Semi-consumer's hedonic test for overall liking of carrots showed that purple and yellow carrots were quite high rated compared with the typical all-orange carrot 'Nebula' (Fig. 1). On the basis of data presented no clear relationship between storage conditions and score for carrots liking can be seen, however. Generally, the results showed that CA-stored samples were rated at least as high as samples stored under normal atmosphere conditions. Since the test was performed in small group of people, there is no fully documented solid basis to draw any wider conclusions, and for this purpose broader consumer's studies should be performed.

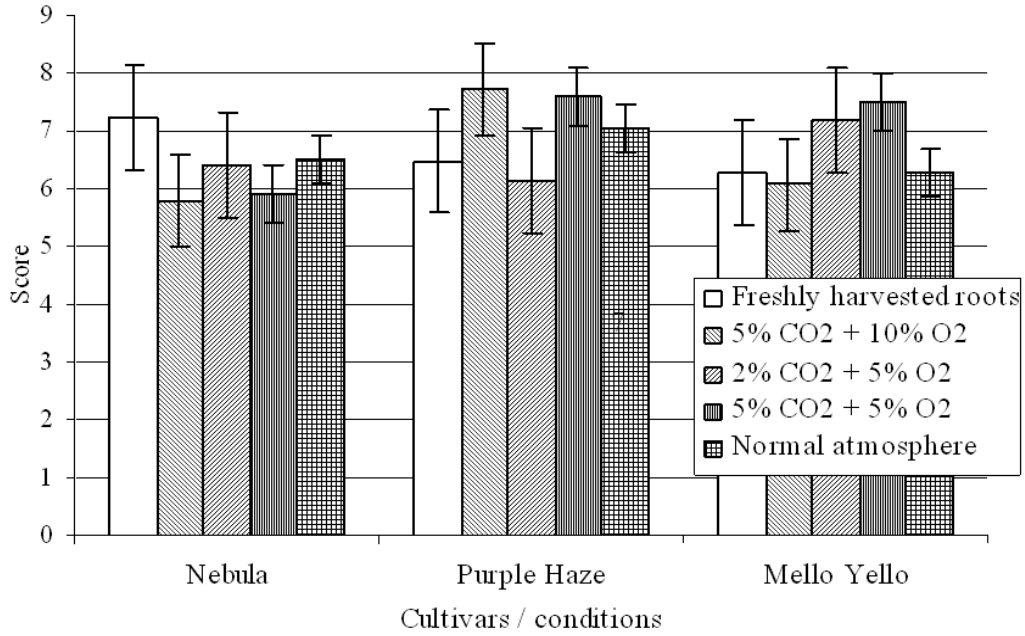


Fig. 1. Overall liking of carrots in semi-consumer's hedonic test of freshly harvested and stored carrot roots in relation to atmosphere composition

Note: vertical bars show standard errors (+/– SE)

Tab. 5. Soluble solids content (°Bx) in freshly harvested and stored carrot roots, in relation to atmosphere composition

| Cultivars | Freshly harvested | After storage at following atmosphere compositions | | | | Means for cultivars |
|---|---|---|---|---|---|---|
| | | 5% $CO_2$+10% $O_2$ | 2% $CO_2$+5% $O_2$ | 5% $CO_2$+5% $O_2$ | Normal atmosphere | |
| 'Nebula' | 8.35 | 7.35 | 7.75 | 7.55 | 7.45 | 7.69 |
| 'Purple Haze' | 11.80 | 10.10 | 10.95 | 10.65 | 10.60 | 10.82 |
| 'Mello Yello' | 9.05 | 8.85 | 8.95 | 8.35 | 8.10 | 8.66 |
| Means for atmospheres | 9.73 | 8.77 | 9.22 | 8.85 | 8.72 | |

LSD P>0.05 for cultivars: 0.51; LSD P>0.05 for atmospheres: 0.21; LSD P>0.05 for interaction: cultivars x atmospheres: n.s.

Soluble solids in carrots roots consist mostly of soluble sugars, and therefore affect sensory sweetness impression. According to the literature sources (Suslow *et al*., 1998; Suojala, 2000; Da Silva *et al.*, 2007) soluble solids content in carrot roots ranged, on average, from 6 to 12 °Bx. It can be seen in Tab. 5 that soluble solids content in roots of the three carrot cultivars was differentiated and ranged (in freshly harvested roots) from 8.35 to 11.80 °Bx. The highest content was found for the roots of 'Purple Haze' carrot and the lowest for 'Nebula'. Alasalvar *et al.* (2001) also reported high sugars content in purple carrot roots. In our study lower content of soluble solids content was observed after storage for all cultivars of carrots. This tendency is in agreement with the data reported by Suojala (2000). We found that storage of the carrots under CA conditions, regardless of the composition of the atmosphere, resulted in higher soluble solids content in the roots than the storage under normal atmosphere. The highest content of soluble solids in the roots was noted for CA 2% $CO_2$+5% $O_2$. The storage under other CA gas compositions resulted in slightly lower soluble solids content, but still higher than storage under normal atmosphere. Despite the tendency to decreasing soluble solids content, the roots showed in some cases higher sweetness after storage than immediately after harvest. The reason is unclear, but it seems that the sweet taste is not directly related to sugars content in the roots, which was pointed out also by other authors (Martens *et al.*, 1983, 1985).

## Conclusions

It can be concluded that investigated carrot cultivars of orange, purple and yellow coloured roots showed different changes in sensory quality as a result of storage. Storage of the carrots under CA positively influenced some sensory quality descriptors of the roots compared with storage at normal atmosphere, and it was especially true for for purple or yellow coloured carrots. Also changes of soluble solids content in the roots were inhibited under CA conditions, which can be the reason of higher sweetness of the CA-stored roots. Taking also into account that CA storage did not cause any increase of off-flavour or off-odour in the roots, this method of storage can be recommended as a useful method for long-term storage of carrot roots of different colour (orange, purple and yellow). CA storage enables keeping the roots quality for a long period without causing undesirable changes in their sensory characteristics (eg. bitterness).

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