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Correlations of carotene with sensory attributes in carrots under different storage conditions

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Abstract

The all-*trans*-α-, all-*trans*-β-, and *cis*-carotene content, measured by HPLC–DAD and the main sensory attributes in two carrot varieties, of the years 2002 and 2003, during storage at 4 °C, 20 °C, −18 °C and −25 °C were determined. At 4 °C, increase of the total carotene content of 8% and 23% were found in the 1st and in the 2nd harvest year, respectively within 14 days of storage. Deep-frozen carrots were characterized as more "juicy", less "tender", "aromatic" and "sweet" compared to fresh carrots in both harvest years. Sensory attributes and chemical data were correlated, and it was shown that the carotene content was positively correlated with the attribute fibrous texture and negatively correlated with the attribute tender texture.

Keywords: Carrots; Carotenes; Storage; Sensory attributes

1. Introduction

Carrots hold an important place in the nutrition of the Western industrial nations because of their high dietary value and generally good storage attributes. According to O'Neill et al. (2001) carrots are the richest source of β-carotene in the European diet, comparing the countries: UK, Republic of Ireland, Spain, France and The Netherlands, in the winter 2001. They are generally the principal dietary source of β-carotene, contributing from 24% (Spain), 38% (France), 42% (The Netherlands), 53% (UK) to 60% (Republic of Ireland) of the total intake. For α-carotene, the values are ranging from 60% (Spain) to 90% (Republic of Ireland).

During storage, carrots are subjected to fresh weight loss depending on several parameters, such as temperature (>4 °C), low humidity (<90 °C relative humidity), the composition of gas in the atmosphere, and methods of packing. But there are also important measurable sensory changes of quality during the storage of carrots (Böttcher & Belker, 1996). These sensory changes can be a result of putrefaction (e.g. by Erwinia-, Botrytis- or Sclerotia-species), a result of the loss of taste because of a decreased sugar content, and above all the result of the formation of bitter off-flavours. The parameter with the greatest changes herein, was the firmness of carrots (Seljåsen, Hoftun, Selliseth, & Bengtsson, 2004; Rosenfeld, Vogt, Aaby, & Olsen, 2004). Moreover, putrefaction led to a bitter, sweet and acidic taste. Furthermore, an earthy odour was clearly detected. The turpentine-like odour had a grassy aroma impact compound. Especially, substances of the terpene fraction and ethanol showed correlations with taste and odour impressions.

Carotene as an important source of vitamin A (especially in population groups and regions with low meat consumption) has already been analysed several times during

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the process of carrot storage (Bajaj, Kaur, Brar, & Sukhija, 1978; Booth, 1951; Kopas-Lane & Warthesen, 1995; Negi & Roy, 2000). However, there has never been an exact examination of the sensory parameters and the carotene content during the same study, varying only temperature and time of the storage.

The aim of this study was to record the most important sensory parameters of two carrot species, to quantify, at the same time, the carotene value and to measure possible correlations. While there already exist correlations of sensory and chemical-analytical data for tomatoes, proven in a series of examinations (e.g. Abegaz, Tandon, Scott, Baldwin, & Shewfelt, 2004), this kind of analysis related to carrots is new.

2. Materials and methods

2.1. Harvesting and preparation of the materials

In the 1st year (2002), carrots of the species Nevis with a diameter of 15–35 mm were harvested on the 15th of October in organic cultivation, from a field near Lommatzsch in Saxonia, Germany by farmers contracted to the Elbtal Frozen Food GmbH company. In the following year, carrots of the species Kingston were harvested on the 24th of October, 2003 using methods that were as closely identifiable with the previous year's study as possible (that means also grown in organic cultivation and with a diameter of more than 15 mm).

Half the amount was then transported on the day of harvesting, in cool-boxes, to the Faculty of Life Sciences, University of Applied Sciences Hamburg for storage at 4 °C and 20 °C, respectively. The other half was blanched under defined conditions (boiling at 95 °C for 65 s) and then submitted to deep-frozen storage at −18 °C or −25 °C (by shock-freezing) in Lommatzsch under the same conditions as used in common industrial production. After the defined storage period (0, 4, 8, and 12 months) the deep-frozen material was, within one day, placed in boxes filled with dry ice and transported from Lommatzsch to Hamburg.

If not immediately analysed, the material was kept refrigerated at −45 °C (at which temperature no physiological changes occured for at least 12 months, according to Bognár & Wolf, 2002).

One part of the entire sample stored at 4 °C was separated after 4 days, the 2nd part after 7 days and the 3rd part after 14 days of storage. One part of the entire sample stored at 20 °C was separated after 4 days and the other after 7 days. Immediately after storage, each sample was cooked according to a defined cooking stage to simulate the domestic method. The deep-frozen stored carrots were also cooked, but they needed shorter cooking times because of the previous blanching step. One part was processed immediately after deep-freezing (stage: 0 m), the other parts of the pool after 4, 8, and 12 months of storage respectively.

The defined cooking process was accomplished as follows: fresh carrots (stored at 4 °C or 20 °C) were cooked in portions of 500 g with 100 g water and 2 g salt for 18 min. Deep-frozen carrots were cooked in portions of 500 g with 100 g water and 2 g salt for 14 min. The cooking time for the deep-frozen carrots is shorter because of the additional blanching step, which is already a pre-cooking step.

For chemical analysis, a representative amount of 100 g of the cooked material was freeze-dried to assure the comparability of long-time stored (and thus dehydrated) states with more aqueous states (e.g. cooked stages). The freeze-dried material was thoroughly pulverised in a mortar to at least 1 mm diameter and analysed for the amount of all-*trans*-α-carotene, all-*trans*-β-carotene, and the amount of the *cis*-carotene isomers.

2.2. Sensory evaluation

Sensory evaluation was performed directly after cooking; each stage of the stored vegetables was separated into one portion to be chemically analysed and another portion which was sensory-evaluated by a trained panel of 12 judges. With the quantitative descriptive analysis, the character and intensity of the defined attributes were measured in three replications. The panel selected 29 descriptive attributes for cooked carrots concerning appearance, odour, taste and texture. The intensities of the attributes were measured on a ten-point-scale. For orientation the scale was divided in the middle. The panellists also worked out detailed definitions for each attribute.

The results were submitted to a statistical analysis of variance (ANOVA) with the LSD (least-significant difference) test.

2.3. Chemical analysis

2.3.1. Reagents and chemicals

All reagents were obtained from Sigma–Aldrich (St. Louis, MO, USA), except for *tert*-butylmethylether, which was obtained from Riedel (Seelze, Germany). All-*trans*-α-carotene was purchased from Carotenature (Lupsingen, Switzerland).

2.3.2. Determination of carotenoids

Freeze-dried (70–80 mg) of carrot powder was squeezed out three times each with 6 ml of methanol p.a., acetone p.a./*n*-hexane, and acetone p.a., respectively, in a 10 ml-centrifuge tube until the carrot powder remained completely white. After each extraction step, the sample was centrifuged and all the supernatants were pooled and filled up with methanol p.a. to a level of 20 ml.

An aliquot was diluted 1:1 in mobile phase 1 (see below) and chromatographed under the following conditions: the mobile phase 1 consisted of methanol/*tert*-butylmethylether/water (81/15/4, v/v/v), the mobile phase 2 consisted of methanol/*tert*-butylmethylether/water (90/6/4, v/v/v).

The mobile phase program was conducted on an HPLC system (LaChrom, 7000 series, Merck Hitachi) with a YMC C_{30} S-5 μm- column with the dimensions of 3×250 mm (including a guard column of YMC C_{30} S-5 μm 3×10 mm) and corresponded, if not mentioned otherwise, with the procedure described by Marx (2000). The column was regulated with a thermostat to 23 °C, the flow was 0.5 ml/min, detection was performed by a diode-array-detector at a monitoring wavelength of 440 nm.

All samples were quantified through external standard calibration (with a concentration of 1–5 mg all-*trans*-β-carotene), whose standard solutions had to be freshly produced every day, because oxygen-induced decomposition was observed and a crystallization of the *trans*-β-carotene-stock-solutions occurred after 1.5 days in the refrigerator.

3. Results and discussion

3.1. Sensory evaluation

Fresh carrots were extraordinarily well storable at 4 °C and 20 °C. Only slight changes of the intensities were found during the first harvest year 2002, where the carrot-typical odour and taste decreased during storage at 4 °C. In 2003, there were no significant changes during 14 days storage at 4 °C. Storage of carrots at 20 °C led in both years to a rubber-like texture.

Comparing fresh and frozen carrots, more differences could be determined. There were altogether nine sensory attributes, which were significantly different by comparing fresh carrots of the 1st day (not stored) with deep-frozen carrots (0 months, not stored). As displayed in Fig. 1, deep-frozen carrots were characterized more "juicy", less "tender", "aromatic" and "sweet" compared to fresh carrots, which was observed during both storage years. The comparison of the influence factors, storage and processing, shows that the changes in quality attributes were mainly caused by the industrial process of blanching and freezing.

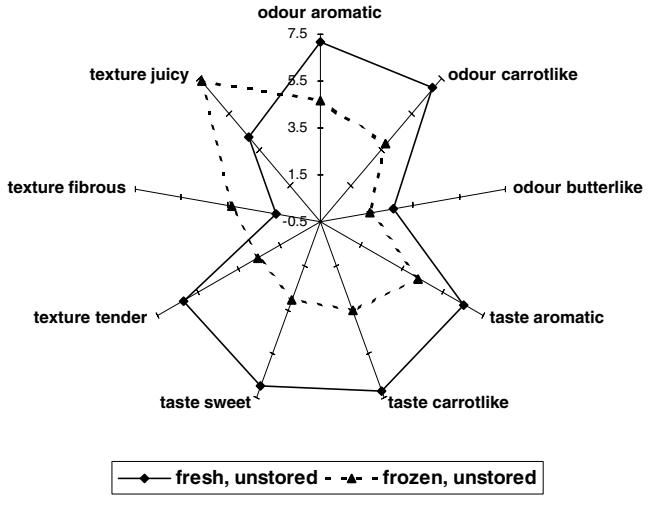

Fig. 1. Fresh carrots compared with carrots immediately after freezing 1st harvest year, variety Nevis (2002).

After 12 months of storage at −18 °C or −25 °C, altogether 12 sensory attributes changed significantly compared to the not stored carrots (0 months) in the 1st harvest year and five sensory attributes in the 2nd harvest year. The attributes that changed almost after 12 months of storage were the "grassy" flavour and the "firm" texture, the intensities of which both decreased. There were no reproducible differences between the storage at a temperature of −18 °C and a temperature of −25 °C during 12 months of storage.

3.2. Chemical analysis

The results of the carotene examinations are presented in Tables 1 and 2, and in Figs. 2 and 3, respectively. They show that considerably less total carotene quantities were determined in the Kingston variety in the 2nd harvest year. However, it should be taken into account that it was impossible to ensure the same weather conditions for both harvests. Rather, the extreme weather conditions (summer 2002 with extreme amounts of precipitation and summer 2003 with many sunny days and continuing dry spells) clearly accounted for the distinct differences in the total carotene quantity.

Furthermore, it was observed that the blanched products (that means the carrots in the deep-frozen condition) presented throughout, a much higher value of total carotene than the fresh unblanched stored ones. This was shown to be true in both harvest years. Responsible for the higher results found in the carrots through different stages of heating, as already observed by many other authors (Bognár, 2003; Granado, Olmedilla, Blanco, & Rojas-Hidalgo, 1992; Khachik & Beecher, 1987; Shaheen, Morsi, Bahgat, & Rofael, 1977), is an increased extraction of protein–chlorophyll-complexes according to Bognár (2003). Another result was that the total carotene concentration increased during storage at 4 °C and 20 °C, while at −18 °C and −25 °C a loss of total carotene during storage could be determined. Similar data can be found in the literature documenting a carotene increase at storage temperatures above the freezing point (Brown, 1949; Bustos Rubio, Matallana González, Orzáez Villanueva, & Marquina, 1992; Howard, Wong, Perry, & Klein, 1999; Kopas-Lane & Warthesen, 1995). In this study, increase of 8% and 23% were found, respectively, in the 1st and in the 2nd harvest year (by comparing the concentration of the 1st day with the concentration of the 14th day) compared to 17% after three days at 4 °C found by Bustos Rubio et al. (1992).

The explanation for the post-harvest increase of the total carotene concentration at 4 °C and at 20 °C should also be found in higher extractability, after enzymatic decomposition processes. The fibrous structure of the carrot matrix could be disaggregated by cellulases and

Table 1
Carotenes in cooked carrots under different storage conditions, 1st harvest year, variety Nevis (2002)

$N = 3$ (°C)	All-*trans*-β-carotene	All-*trans*-α-carotene	Sum of all *cis*-isomers	Total standard deviation	Total carotenoids
1st day	134.8	85.8	4.7	1.7	225.3
4th day 4	133.6	85.4	5.4	1.9	224.4
7th day 4	137.8	84.7	6.7	4.6	229.1
14th day 4	136.7	83.1	2.2	5.0	222.0
4th day 20	136.2	85.9	3.7	8.2	225.8
7th day 20	148.8	88.6	5.4	8.0	242.8
0 month[a]	166.2	102.0	3.7	7.6	271.9
4th month −18	153.8	89.6	1.9	3.8	245.3
8th month −18	148.9	90.8	3.5	4.2	243.1
12th month −18	145.9	88.0	2.8	3.4	236.6
4th month −25	169.9	96.0	2.9	4.6	268.7
8th month −25	161.9	94.2	2.5	2.4	258.5
12th month −25	155.8	93.4	2.3	2.5	251.4

[a] Material was blanched, shock-frozen and analyzed directly thereafter, or after preservation at −45 °C, respectively.

Table 2
Carotenes in cooked carrots under different storage conditions, 1st harvest year, variety Kingston (2003)

$N = 3$ (°C)	All-*trans*-β-carotene	All-*trans*-α-carotene	Sum of all *cis*-isomers	Total standard deviation	Total carotenoids
1st day	83.9	50.3	2.2	9.5	136.3
4th day 4	72.4	40.9	2.5	8.5	115.8
7th day 4	108.8	56.2	2.2	5.7	167.1
14th day 4	89.6	52.4	2.7	14.6	144.6
4th day 20	82.3	45.5	2.0	16.5	129.8
7th day 20	91.8	42.6	1.6	22.1	135.9
0 month[a]	113.5	52.4	2.7	6.1	168.6
4th month −18	95.8	49.0	3.1	4.1	147.9
8th month −18	102.5	51.2	2.9	6.5	156.6
12th month −18	96.2	50.1	1.8	4.2	148.1
4th month −25	98.4	41.2	1.7	3.9	141.3
8th month −25	95.7	49.2	2.0	5.5	146.9
12th month −25	100.6	49.9	2.0	3.9	152.4

[a] Material was blanched, shock-frozen and analyzed directly thereafter, or after preservation at −45 °C, respectively.

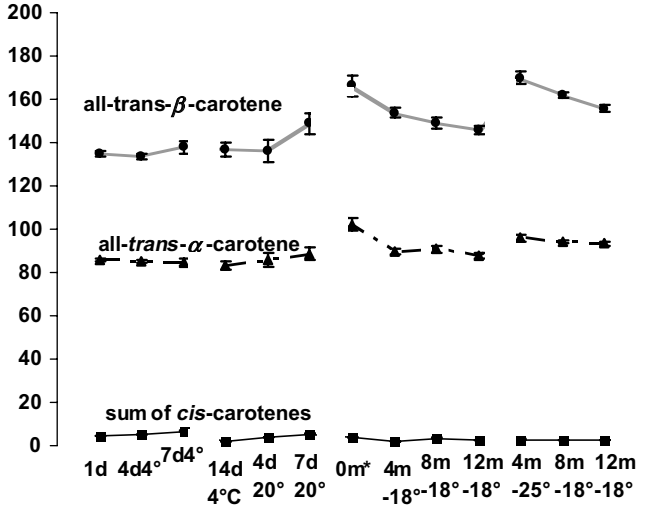

Fig. 2. Carotenes in cooked carrots under different storage conditions, 1st harvest year, variety Nevis (2002).

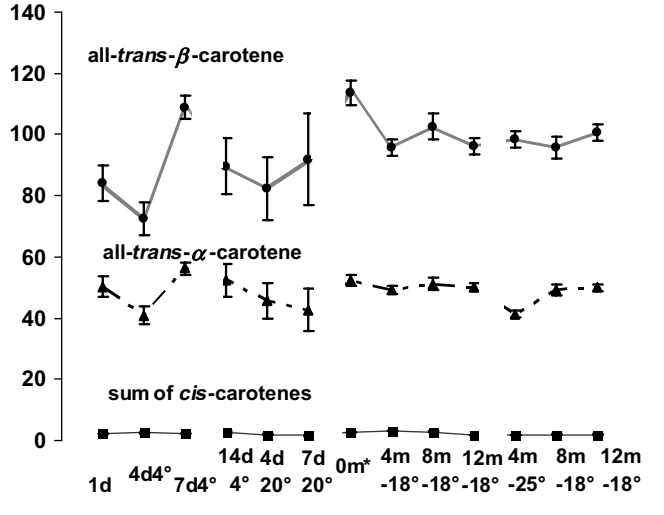

Fig. 3. Carotenes in cooked carrots under different storage conditions, 1st harvest year, variety Kingston (2003).

hemicellulases and further quantities of carotene could be released during the extraction process. However, it should be noted at this point that even after three extraction stages (including an ultra-sonic treatment) and a further 4th extraction step, no more carotene quantities were extractable.

Some authors with similar observations even assume that carotene is formed in the carrots after the harvest (Booth, 1951; Bustos Rubio et al., 1992; Rodriguez-Amaya, 1997). A carotenogenesis after the harvest has been proven in many climacteric fruits, e.g. tomatoes or mangoes, but also in tuberous vegetables, such as sweet potatoes (Ezell, Wilcox, & Crowder, 1952).

3.3. Correlation of sensory with chemical parameters

The correlation of the sensory with the chemical data were carried out with the Partial Least Square Regression analysis.

PLSR is a method, that is, increasingly used in the application and interpretation of vast data records. The method is a combination of a modified principal component analysis (PCA) and multiplied correlation. The correlation was accomplished using "The Unscrambler®" software (Camo, 2004). Since the dimensions of the variables (sensory attributes, chemical data) were different, the data were standardized by the "Unscrambler®" software. In order to carry out the PLSR, only these sensory and chemical–analytical data were used, concerning the significant changes during storage (through an analysis of variance). The averages of the sensory profile examinations were used for the PLSR.

The results show that only texture attributes correlate significantly with the carotene content. It correlates positively with the attribute fibrous texture and negatively with the tender texture. Carrots with a high carotene content are apparently more solid and less tender. The correlations of these marked attributes are significant.

Other sensory attributes did not show strong positive or negative correlations or were not significant.

Through the PLSR-regression 66% of the *Y*-variable (carotene-content) are explained, and the calculated regression coefficient is 0.93. In the 2nd harvest year, there was no significant correlation of the carotene-content with the sensory parameters. A general statement concerning the correlation of carotene with either a tender or firm texture can therefore, not be made.

4. Conclusion

This study showed that the carotene content in carrots proved to be highly stable in the uncrushed matrix. It has also been shown that fresh carrots are suited for storage at the conditions chosen in this study. Only slight changes occurred during storage of the carrots for seven and fourteen days, respectively at 20 °C and 4 °C.

Concerning the sensory quality, losses comparing the unstored fresh carrots with the unstored frozen ones directly after processing ("0 months") were observed. An average correlation of $R = 0.93$ of the attributes tender texture and fibrous texture with the carotene content was indicated.

It was shown, that the storage capacities of carrots stored at all temperatures investigated at (4 °C, 20 °C, −18 °C and −24 °C) were extraordinary good, as there were no significant losses in the carotene content and only slight changes in the sensory profile (loss of the carrot-like odour/taste and formation of a rubber-like texture) occurred.

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References

Abegaz, E. G., Tandon, K. S., Scott, J. W., Baldwin, E. A., & Shewfelt, R. L. (2004). Partitioning taste from aromatic flavor notes of fresh tomato (*Lycopersicon esculentum*, Mill.) to develop predictive models as a function of volatile and nonvolatile components. *Postharvest Biology and Technology, 34*, 227–235.

Bajaj, K. L., Kaur, G., Brar, J. S., & Sukhija, B. S. (1978). Chemical composition and keeping-quality of carrot (*Daucus carota* L.) varieties. *Plant Foods for Man, 2*, 159–165.

Bognár, A. (2003). Vitaminveränderungen bei der Lebensmittelverarbeitung im Haushalt. *Ernährung im Fokus, 3*, 330–335.

Bognár, A. A., & Wolf, W. (2002). Zur Lagerstabilität und Qualität tiefgefrorener Lebensmittel. *Ernährung im Fokus, 2*, 143–149.

Booth, V. H. (1951). Chromogenesis in stored carrots. *Journal of the Science of Food and Agriculture, 2*, 353–358.

Böttcher, H., Belker, N. (1996). *Frischhaltung und Lagerung von Gemüse*. Eugen Ulmer, Stuttgart.

Brown, G. B. (1949). The effect of winter storage on the carotene content of carrot varieties. *Proceedings of the American Society for Horticultural Science, 54*, 304–306.

Bustos Rubio, A., Matallana González, M. C., Orzáez Villanueva, M. T., & Marquina, D. (1992). Incidencia de la accion del frio sobre el contenido en β-caroteno en vegetales. *Alimentaria, 35*, 35–39.

Ezell, B. D., Wilcox, M. S., & Crowder, J. N. (1952). Pre- and post-harvest changes in carotene, total carotenoids, and ascorbic acid content of sweet potatoes. *Plant Physiology, 27*, 355–369.

Granado, F., Olmedilla, B., Blanco, I., & Rojas-Hidalgo, E. (1992). Carotenoid composition in raw and cooked spanish vegetables. *Journal of Agriculture and Food Chemistry, 40*, 2135–2140.

Howard, L. A., Wong, A. D., Perry, A. K., & Klein, B. P. (1999). β-Carotene and ascorbic acid retention in fresh and processed vegetables. *Journal of Food Science, 64*, 929–936.

Khachik, F., & Beecher, G. (1987). Application of a C-45-β-carotene as an internal standard for the determination of carotenoids in yellow/orange vegetables by liquid chromatography. *Journal of Agriculture and Food Chemistry, 35*, 732–738.

Kopas-Lane, L. M., & Warthesen, J. J. (1995). Carotenoid photostability in raw spinach and carrots during cold storage. *Journal of Food Science, 60*, 773–776.

Negi, P. S., & Roy, S. K. (2000). Effect of low-cost storage and packaging on quality and nutritive value of fresh and dehydrated carrots. *Journal of the Science of Food Agriculture, 80*, 2169–2175.

O'Neill, M. E., Carroll, Y., Corridan, B., Olmedilla, B., Granado, F., Blanco, I., et al. (2001). A European carotenoid database to assess carotenoid intakes and its use in a five-country comparative study. *British Journal of Nutrition, 85*, 499–507.

Rodriguez-Amaya, D. B., 1997. Carotenoids and food preparation: the retention of provitamin A carotenoids in prepared, processed, and stored foods. <www.mostproject.org/carrots2.pdf> (10.09.04).

Rosenfeld, H. J., Vogt, G., Aaby, K., & Olsen, E. (2004). Interaction of terpenes with sweet taste in carrots. *Acta Horticulture, 637*, 377–386.

Seljåsen, R., Hoftun, H., Selliseth, J., & Bengtsson, G. B. (2004). Effects of washing and packing on sensory and chemical parameters in carrots (*Daucus carota* L.). *Journal of the Science of Food and Agriculture, 84*, 955–965.

Shaheen, A., Morsi, M. K. S., Bahgat, M. A., & Rofael, N. (1977). Effect of processing on β-carotene content on carrots. *Journal of Drug Research Egypt, 9*, 19–26.