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Original Research Article

Carotenoid database of commonly eaten Swiss vegetables and their estimated contribution to carotenoid intake

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ABSTRACT

Carotenoids are plant pigments which are thought to decrease the risk of degenerative diseases via their antioxidant properties. The aim of this work was to create a carotenoid database for clearly identified Swiss vegetables, grown under known conditions and analyzed using a standardized protocol. We determined the six major carotenoids in the vegetables most frequently consumed in Switzerland. Chlorophyll a and b were additionally measured in green leafy vegetables. Lutein and β-carotene concentrations in green leafy vegetables ranged from 0.2 to 13 mg and 0.2 to 8 mg/100 g fresh matter, respectively, with the highest total carotenoid contents in *Brassicaceae*. Additionally, we identified strong correlations ($R^2 > 0.9$) between the lutein and β-carotene concentrations and the total chlorophyll contents in different botanical families. Orange and red vegetables contained a greater diversity of carotenoids, with α- and β-carotene being the predominant carotenoids in orange carrots and lycopene in tomatoes. Peppers additionally contained zeaxanthin and β-cryptoxanthin. Based on these data, and on the estimated consumption of the different vegetables in Switzerland, we estimate that 3.3 mg β-carotene, 2.2 mg lycopene and 1.8 mg lutein are consumed daily from fresh vegetables.

1. Introduction

Carotenoids are a large group of fat-soluble pigments which are intensely coloured and usually responsible for the yellow, orange and red colours in fruits and vegetables. In green leafy vegetables, this colouration is covered by the green and blue of chlorophyll a and b. To date, 700 carotenoids have been identified, of which only 50 are regularly consumed in the human diet and 24 have so far been detected in human plasma (Maiani et al., 2009). The beneficial effects of a diet rich in carotenoids have been extensively documented in the literature. Besides the function of some carotenoids as precursors of vitamin A, carotenoids are valuable antioxidants (Palozza and Krinsky, 1992), and a high dietary intake and increased blood concentrations have been associated with a decrease in the risk of degenerative diseases such a cardiovascular diseases (Granado et al., 2003), specific types of cancer (Finley, 2005; Seifried et al., 2003; Tang et al., 2005b), age related macular degeneration (Seddon et al., 1994) and cataract formation (Brown et al., 1999; Chasan-Taber et al., 1999). In Western diets, the most abundant carotenoids are the three oxygenated xanthophylls lutein, zeaxanthin and β-cryptoxanthin and the three major carotenes, α-carotene β-carotene and lycopene.

The daily intake of carotenoids has been stated to vary between 9.5 mg in Spain and 16.1 mg in France (O'Neill et al., 2001). With regard to the fruit and vegetable intake, the carotenoid concentrations and patterns can vary strongly between European countries.

To date, no carotenoid intake data have been reported for the Swiss population. According to the 5th Swiss nutrition report (Gremaud et al., 2005), the vegetables most consumed in Switzerland are green leafy vegetables (21.7 kg/person/year) – composed mainly of salads, Swiss chard and spinach – followed by tomatoes (10.2 kg/person/year) and carrots (9.2 kg/person/year). Green leafy vegetables are high in lutein and β-carotene, tomatoes in lycopene and carrots in α- and β-carotene. Although there are previous reports from different countries on the carotenoid content of fruits and vegetables, the data are difficult to interpret due to (i) incomplete identification of the vegetables analyzed, (ii) differences in the agronomic practices and growing environment and (iii) quantification using different analytical methods.

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The carotenoid dataset for different vegetables in the present study was produced using a single analytical technique (extraction and HPLC) for different vegetable cultivars clearly identified by their botanical classification. For some vegetable cultivars, we determined the carotenoid contents of two or more different genetic variations within one species, so as to quantify the within species variability in vegetable cultivars cultivated under identical environmental conditions. Based on a known positive correlation between carotenoids and chlorophylls, we additionally measured the chlorophyll a and b concentrations in green leafy vegetables, with the intention to assess the potential of quantifying the carotenoid content by measuring the green colouration.

2. Materials and methods

2.1. Samples

One hundred and seven different vegetable cultivars commonly produced and eaten in Switzerland and belonging to the botanical families *Asteraceae*, *Apiaceae*, *Brassicaceae*, *Chenopodeaceae*, *Liliaceae* and *Solanaceae* were analyzed. The individual vegetables with their botanical classification (species, variety and cultivar) are listed in Tables 1 and 2. All vegetable cultivars were grown at the Research Station in Wädenswil, Switzerland under conventional growing conditions in open fields with the exception of tomatoes and peppers, which were cultivated in the greenhouse. They were harvested at full ripeness and stored at 1 °C until pre-treatment, which was conducted within 6 h. The samples were washed with cold water, dripped in a commercial salad centrifuge and finally inedible parts (i.e. rotten leaves or lignified parts, but not outer dark green leaves) were removed with a kitchen knife. In general, the sample for analysis consisted of the edible part of 12 replicate samples of each individual vegetable. Each replicate was sliced into four quarters with a kitchen knife. Two opposite quarters were immediately frozen in liquid nitrogen (Messer Schweiz AG, Lenzburg, Switzerland) and all 24 pieces were pooled as a representative sample. The frozen vegetables were abrasively crushed in a dry ice mill (Meidinger AG, Kaiseraugst, Switzerland), ground with a cutter at 1 °C to a fine powder (La Moulinette DPA 1, Germany) and finally stored in amber-coloured bottles at −20 °C until extraction. The loose leafy vegetables, such as the Japanese Greens and rocket cultivars, chives, scallion, spinach and chard were harvested in representative amounts (1–5 kg batches), washed as described above and mixed in a box. An aliquot of 500–750 g was directly flushed with liquid nitrogen and ground with a cutter as described above. The frozen powders were also stored at −20 °C in amber-coloured bottles.

2.2. Extraction

Methanol and acetone (Acros Organics Chemie Brunschwig, Basel, Switzerland) with a purity >99%, were mixed 1:1 (v:v) and the extraction solvent was completed by adding 50 μl of 2,6-di-tert-buthyl-methylphenol (Sigma–Aldrich Chemie GmbH, Buchs, Switzerland) per litre to prevent oxidation. For extraction, aliquots (5 g) of the frozen powder were mixed with 60 ml of the extraction solvent, flushed with nitrogen for 30 s and homogenized with a Polytron (Polytron PT 3100, MERCK, Zug, Switzerland) at maximum speed for another 30 s. The extracts were made up to 100 ml with additional extraction solvent and allowed to stand for 5 min for sedimentation.

For HPLC analysis, an aliquot of the supernatant was filtered through 0.45 μm nylon filters (OPTI–Flow®, WICOM, Heppenheim, Germany) directly into an HPLC vial. The extraction was done in duplicate.

Table 1
Lutein and β-carotene concentrations (mg/100 g edible FM; mean values of duplicates) in selected Swiss green leafy and *Liliaceae* vegetable cultivars according to botanical classification.

Botanical family / Species	Variety / Cultivar	Lutein	β-Carotene
Asteraceae			
Cichorium endivia L.	*var. crispum*		
	endive St Laurent frisée	2.98	1.86
Cichorium intybus L.	*var. foliosum*		
	chicory Mailänder	3.35	1.96
	chicory Palla Rossa Prima	1.76	1.05
	chicory Rote von Treviso	4.37	2.39
	chicory Rouge de Veron	6.98	4.16
Cichorium intybus L.	*var. partim*		
	catalogna Blanche de Milan	2.83	1.77
	catalogna Cioria della Catalogna	6.66	3.93
	catalogna Rossa	7.88	4.52
	catalogna Selvatica da Campo	8.40	4.88
	catalogna Trévise	4.99	2.93
	chioggia Clause No.12	8.14	4.81
	chioggia Marsica	2.93	1.64
Lactuca sativa L.	*var. capitata*		
	batavia lettuce (green), Lirice	1.34	1.52
	batavia lettuce (green), Malabo	0.62	0.75
	batavia lettuce (red), Mohican	1.24	1.35
	batavia lettuce (red), RZ 81-69	1.67	1.65
	batavia lettuce (red), Starksy	1.45	1.56
	head lettuce (green), BRP 6621	1.07	1.20
	head lettuce (green), Veronique	0.66	0.70
	head lettuce (red), Sebastiano	2.03	2.15
	head lettuce (red), Tuareg	0.40	0.48
	iceberg lettuce (green), Diamantinas	0.42	0.47
	iceberg lettuce (green), Realist	0.21	0.29
	iceberg lettuce (green), Stylist	0.77	0.80
	salanova lettuce (green), Seneca	1.14	1.15
	salanova lettuce (green), Trioletta	0.80	0.84
	salanova lettuce (red), Robinio	1.45	1.51
	salanova lettuce (red), Gaugin	2.60	2.30
Lactuca sativa L.	*var. crispa*		
	lollo rosso lettuce (red), Carmesi	2.55	2.37
	lollo rosso lettuce (red), Cavarnet	1.89	2.02
	lollo rosso lettuce (red), Solmar	1.59	1.80
	lollo verde lettuce (green), Aleppo 1	1.12	1.20
	lollo verde lettuce (green), Bartoli	1.20	1.31
	lollo verde lettuce (green), Granite	1.43	1.45
	oak leaf lettuce (green), Bassoon	1.43	1.51
	oak leaf lettuce (green), Quenty	1.34	1.50
	oak leaf lettuce (red), Murai	1.07	1.19
	oak leaf lettuce (red), Rougini	1.07	1.25
Lactuca sativa L.	*var. longifolia*		
	mini romaine lettuce (green), Scooby	0.87	0.93
	mini romaine lettuce (green), Sweetheart	2.05	2.20
	mini romaine lettuce (red), Cegolain	2.00	1.90
	mini romaine lettuce (red), Mordore	1.28	1.78
	romaine lettuce (green), Marizal	1.34	1.50
	romaine lettuce (green), Quintus	1.03	1.05
	romaine lettuce (green), Rom 209	1.56	1.73
	romaine lettuce (green), Rom 9009	1.09	1.22
Brassicaceae			
Brassica juncea L.	*var. rugosa*		
	asia leaf salad Red Giant	5.62	5.05
	leaf mustard Bloody Mary	6.54	5.60
Brassica oleracea L.	*var. botrytis*		
	broccoli	1.04	0.68
	romanesco	0.34	0.20
Brassica oleracea L.	*var. capitata f. alba*		
	white cabbage Dutchy	0.82	0.40
	white cabbage Filderkraut	0.73	0.73
	white cabbage Isa	0.45	0.23
Brassica oleracea L.	*var. gemmifera*		
	brussels sprouts Camus	0.36	0.23
	brussels sprouts Cornus	0.29	0.17
	brussels sprouts SG 1403	0.35	0.20
	brussels sprouts SG 2335	0.43	0.26