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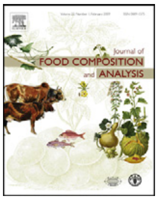

Original Article

Xanthophyll (lutein, zeaxanthin) content in fruits, vegetables and corn and egg products☆

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ABSTRACT

Lutein and zeaxanthin are carotenoids that are selectively taken up into the macula of the eye where they are thought to protect against the development of age-related macular degeneration. Current dietary databases make it difficult to ascertain their individual roles in eye health because their concentrations in foods are generally reported together. The objective of this work is to determine the concentrations of lutein and zeaxanthin, separately, within major food sources of dietary xanthophylls as determined by NHANES 2001–2002 intakes. Corn and corn products were found to be major contributors of dietary zeaxanthin whereas green leafy vegetables were major contributors of dietary lutein. The predominant isomeric xanthophyll form was *trans* for all foods. Processed foods contained more *cis* xanthophyll isomers than fruits and vegetables. These data will provide added information to the current databases for lutein and zeaxanthin content of commonly consumed foods as well as enhance the validity of estimates of dietary intake of these xanthophylls and their respective contributions to health.

1. Introduction

The xanthophylls lutein and zeaxanthin are plant pigments that selectively accumulate in the macula of the retina of the eye where they are thought to protect against the development of age-related macular degeneration (AMD) (Bone and Landrum, 1992; Snodderly, 1995). In the macula, lutein and zeaxanthin are collectively referred to as macular pigment (Bone et al., 1985). The presence of lutein and zeaxanthin in human blood and tissues is entirely due to the ingestion of food sources containing these xanthophylls. The mechanisms by which lutein and zeaxanthin are thought to provide protection to the eye are through their roles as blue light filters and/or as antioxidants (Snodderly, 1995).

Given that the central region of the retina is prone to the destructive effects of AMD and that the distribution of lutein and zeaxanthin differ within the macula (with a higher ratio of zeaxanthin:lutein centrally), there is discussion on their individual roles in eye health. Of the two, lutein predominates over zeaxanthin in a typical diet (Sommerburg et al., 1998; USDA, 1998).

Accurate assessments of individual intakes of lutein and zeaxanthin are crucial in the evaluation of the relative roles in eye health. This is difficult given that current databases generally report these carotenoids together (Humphries and Khachik, 2003; USDA, 1998). Of note is the limited information on corn and egg food products (West and Poorvliet, 1993). This is of particular interest given that for many a significant source of dietary xanthophylls may come from these products (Bermudez et al., 2005; Humphries and Khachik, 2003; West and Poorvliet, 1993). Corn stands apart from other vegetables in that the relative amount of zeaxanthin is more (Humphries and Khachik, 2003). Eggs and egg products are of interest because of the high bioavailability of xanthophylls from this food source (Chung et al., 2004).

In this study, corn and egg food products, fruits and vegetables were analyzed for these two carotenoids along with the other major dietary carotenoids (cryptoxanthin, β-carotene, α-carotene, lycopene). Foods were selected based not only on xanthophyll content but also on the amount and frequency of consumption using NHANES 2001–2002 intake data (Food Surveys Research and Group, 2006). In the past, lutein and zeaxanthin have been considered together. It is essential to be able to determine their contributions to diet when considering their respective roles in eye health.

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2. Materials and methods

2.1. Sample preparation

Commonly consumed fruits, vegetables and corn and egg food products were purchased from local grocery stores (Stop n Shop Supermarkets). Table 1 contains scientific names for the fruits and vegetables analyzed. Food preparation protocol followed standard cooking/handling procedures as established by the Metabolic Research Kitchen at our Nutrition Center. Boiled eggs, egg and spinach noodles and Kraft macaroni and cheese were prepared in our quality food production area as part of our larger research recipe production according to standard cooking/boiling protocols or product instructions (Kraft boxed instructions). Noodles, macaroni and cheese, and egg yolk were weighed after cooking. All vegetables were weighed before and after cooking. Scallions (100 g) were fried in oil in a non-stick pan, with 15 g olive oil (Pure Olive Oil, Catania-Spagna, Corp. Ayer, MA) added to the pan. All cooked vegetables had 10–15 g water added to the microwaveable dish and were placed in an industrial microwave (Panasonic Genius Sensor 1350W), covered with plastic film, vented and heated for 60–90 s. For frozen items, 100 g portions were weighed while frozen (Mettler Toledo Balance Scale PG 2002-S), with the exception of frozen spinach. The spinach was partially thawed in a light–protected container and then weighed. Food samples were transferred for cooking to the microwave, in the opaque container and then covered with a vented plastic wrap cover. All were cooked for 45 s before being checked by food probe thermometer, and then heated until each item reached 155–160 °F. Those vegetables that required extra water added for cooking are identified in Table 2. Details on food preparation are given in Table 2.

Table 1
Common foods and scientific name.

Common food	Scientific name
Apple, red delicious	*Malus domestica*
Apricot, dried	*Prunus armeniaca*
Artichoke, globe (heart)	*Cynara acolymus*
Asparagus, cooked	*Asparagus officinalis*
Broccoli, cooked (flowers and stems)	*Brassica oleracea* var. *italica*
Brussel sprouts, cooked (from frozen)	*Brassica oleracea* var. *Gemnifera*
Cabbage, red	*Brassica oleracea* var. *capitata*
Cantaloupe, raw	*Curcubita melo*
Cilantro (Chinese parsley)	*Coriander sativum*
Cucumber	*Cucumis sativus*
Endive	*Cichorium endiva*
Grapes, green	*Vitis vinifera*
Grapes, red	*Vitis vinifera*
Green beans, cooked from frozen	*Phaseolus vulgaris*
Honeydew	*Curcumis melo*
Kale, cooked	*Brassica oleracea* var. *acephala*
Kiwi (Kiwifruit, Chinese gooseberry)	*Actinidia chinensis*
Lettuce, iceberg	*Latuca sativa* (crisphead)
Lettuce, romaine	*Latuca sativa* (Cos)
Lima beans, cooked	*Phaseolus lunatus*
Mango	*Mangifera indica*
Nectarine	*Prunus persica*
Olive, green	*Olea europea*
Orange juice	*Citrus sinensis* (juice of)
Parsley	*Petroselinum crispum*
Peach, canned	*Prunus persica*
Peach, raw	*Prunus persica*
Pepper, green (Bell)	*Capsicum annuum*
Pepper, orange (Bell)	*Capsicum annuum*
Pepper, red (Bell)	*Capsicum annuum*
Pepper, yellow (Bell)	*Capsicum annuum*
Scallions, raw	*Allium cepa*
Scallions, cooked in oil	*Allium cepa*
Spinach, cooked	*Spinacia oleracea*
Spinach, raw	*Spinacia oleracea*
Squash, acorn, cooked	*Curcubita moschata*; c maxima
Squash butternut, cooked	*Curcubita moschata*; c maxima
Squash, yellow, cooked	*Curcubita pepo*
Watermelon	*Citrullus vulgaris*
Zucchini, cooked	*Curcubita pepo*

2.2. Analysis of carotenoids

Carotenoids were extracted using previously published methods with slight modifications (Riso and Porrini, 1997). Methanol (5 mL) was added to an accurately weighed food sample ($\sim$1 g) in a 50-mL glass vial. The sample with the added methanol was then homogenized and then left to incubate overnight (16 h) in a refrigerator at 4 °C. After incubation, the sample was centrifuged at $800 \times g$ for 10 min. The methanol layer was transferred to a 25-mL volumetric flask. After the addition of 5 mL tetrahydrofuran (THF), the vial was vortexed for 30 s, followed by a centrifugation at $800 \times g$ for 5 min. The THF layer was transferred into the methanol containing volumetric flask. The sample was extracted three more times using the same procedures and the THF layers were combined into the volumetric flask. THF was added to make the final volume 25 mL. Then 10 mL (40% of the total) of extract was dried under nitrogen. For the spinach sample 5 mL was dried because of the relatively higher xanthophyll concentration. The extract was resuspended in 500 μL of ethanol. If the suspension appeared cloudy, oily or non-homogeneous (in the case of foods containing a relatively high fat), the extraction was repeated and ethanol:methyl-*tert*-butyl ether (MTBE) (2:1, v/v) or MTBE:methanol (2:1, v/v) was selected for the suspension solvent. After resuspension, the extract was vortexed for 30 s. Twenty-microliter samples were injected into the HPLC system for carotenoid analysis.

2.3. HPLC analysis

The carotenoids were quantified as previously described, with minor modifications (Chung et al., 2004), using a C30 column (3 μL, 150 mm × 4.6 mm, YMC, Wilmington, NC). All carotenoids were monitored at 445 nm with Waters 2996 photodiode array detector (Milford, MA). The HPLC mobile phase was methanol:MTBE:water (95:3:2, v/v, with 1.5% ammonium acetate in water, solvent A) and methanol:MTBE:water (8:90:2, v/v, with 1.0% ammonium acetate in water, solvent B). The gradient procedure, at a flow rate 0.4 mL/min (10 °C), was as follows: (1) start at 100% solvent A, (2) a 21-min linear gradient to 45% solvent A and 55% solvent B, (3) 1-min hold at 45% solvent A and 55% solvent B, (4) an 11-min linear gradient to 5% solvent A and 95% solvent B, (5) a 4-min hold at 5% solvent A and 95% solvent B, (6) a 2-min linear gradient back to 100% solvent A, and (7) a 28-min hold at 100% solvent A. Lutein, zeaxanthin, crypoxanthin, α-carotene, all-*trans*-β-carotene, 9- and 13-*cis*-β-carotene, 5-, 9-, 13-, and 15-*cis*- and *trans*-lycopene were adequately separated by using this method. Peak identification in food samples was based on comparisons with retention time and absorption spectra of known carotenoid standards (β-carotene and lycopene from Aldrich–Sigma Chemical Co.; lutein, zeaxanthin, and β-cryptoxanthin from DSM Nutritionals). Carotenoids were quantified by integrating peak areas in the HPLC chromatograms. Each food was analyzed in duplicate. If analysis of duplicate samples were different by more that 10%, it was repeated in duplicate and all analyses were used. Carotenoid analysis was performed two to six times. These foods are indicated in the appropriate table. The %CV was less than 10% for foods analyzed more than twice. The final results were expressed in μg/100 g.

Table 2
Sample preparation.

Food	Form	Preparation	Extra water, distilled	Cooking	Manufacturer/brand
Fruits					
Artichoke	Canned, drained	None	None	None	Stop n Shop
Asparagus	Frozen	Microwave	28 g	75 s	Stop n Shop
Broccoli	Frozen, stems and flowers	Microwave	28 g	75 s	Sysco$^{\text{TM}}$ Corp
Brussel sprouts	Frozen	Microwave	None	75 s	Stop n Shop brand
Butternut squash	Frozen, peeled, cubed 1	Microwave	28 g	60 s	Stop n Shop brand
Cabbage, red	Raw, leaves	Raw	None	None	Stop n Shop
Spinach	Frozen	Microwave	56 g	60 s	Sysco$^{\text{TM}}$ Corp
Carrots	Frozen, peeled rounds	Microwave	28 g	90 s	Sysco$^{\text{TM}}$ Corp
Carrots	Raw, peeled rounds	Raw	None	None	Stop n Shop
Corn	Frozen, off cob	Microwave	None	60 s	Sysco$^{\text{TM}}$ Corp
Cucumber	Raw, sliced	Raw	None	None	Stop n Shop
Endive	Raw leaves	Raw	None	None	Stop n Shop
Green beans	Frozen, cut	Microwave	28 g	90 s	Sysco$^{\text{TM}}$ Corp
Kale	Fresh, chopped leaves	Microwave	56 g	90 s	Local produce
Lettuce, iceberg	Raw leaves	Raw	None	None	Stop n Shop
Lettuce, romaine	Raw leaves	Raw	None	None	Stop n Shop
Lima beans	Canned, drained	Microwave	None	60 s	Sysco$^{\text{TM}}$ Corp
Okra	Frozen, sliced	Microwave	28 g	60 s	Stop n Shop brand
Peas	Frozen	Microwave	28 g	75 s	Sysco$^{\text{TM}}$ Corp
Pepper, green	Raw, chopped	Raw	None	None	Stop n Shop
Pepper, orange	Raw, chopped	Raw	None	None	Stop n Shop
Pepper, red	Raw, chopped	Raw	None	None	Stop n Shop
Pepper, yellow	Raw, chopped	Raw	None	None	Stop n Shop
Scallions	Fresh, chopped	Stovetop, cooked in 15 g olive oil	None	8 min	Stop n Shop
Scallions	Raw, chopped	Raw	None	None	Stop n Shop
Spinach	Frozen	Microwave			
Spinach	Raw leaves	Raw	None	None	Stop n Shop
Squash, acorn	Raw, peeled, cubed 1	Microwave	28 g	60 s	Stop n Shop brand
Squash, zucchini	Frozen, sliced with skin	Microwave	56 g	60 s	Sysco$^{\text{TM}}$ Corp
Squash, yellow (summer)	Frozen, sliced, with skin	Microwave	56 g	60 s	Stop n Shop
Herbs					
Cilantro	Raw, sprigs, no stems	Raw	None	None	Stop n Shop
Curly Parsley	Raw, sprigs, no stems	Raw	None	None	Stop n Shop
Fruits					
Apple, red delicious	Raw, with skin	Raw	None	None	Stop n Shop
Apricot	Dried	Dried	None	None	Sysco$^{\text{TM}}$ Corp
Cantaloupe	Raw	Raw	None	None	Stop n Shop
Grapes, green	Raw	Raw	None	None	Stop n Shop
Grapes, red	Raw	Raw	None	None	Stop n Shop
Honeydew melon	Raw	Raw	None	None	Stop n Shop
Kiwi	Raw, peeled	Raw	None	None	Stop n Shop
Mango	Raw, peeled	Raw	None	None	Stop n Shop
Nectarine	Raw, peeled sections	Raw	None	None	Stop n Shop
Olive, green (*Pitted manzanilla*)	Bottled in brine	None	None	None	Sysco$^{\text{TM}}$ Corp
Orange juice, 100% juice	Made from concentrate	None	None	None	Ardmore Farms, Akron, Ohio
Peach	Raw with peel	Raw	None	None	Stop n Shop
Peach, canned	Peeled, canned in own juice	Canned	None	None	Northeast Marketing
Pumpkin	Canned	None	None	None	Sysco$^{\text{TM}}$ Imperial Solid pack from #10 can (106 oz)
Watermelon	Raw without rind	Raw	None	None	
Other					
Bread, white sliced	Shelf stable, prepared	None			Sysco$^{\text{TM}}$ Corp
Cornmeal, yellow	Shelf stable uncooked	Raw	None		Aunt Jemima Yellow Cornmeal
Cornmeal, white	Shelf stable uncooked	Raw	None		Quaker Oats, Chicago Il
Corn muffin	Shelf stable, prepared	None-bakery prep			Sysco$^{\text{TM}}$ Corp
Spinach noodles	Cooked	Stovetop boiled	800 g water to 100 g noodles		Stop n Shop
Egg	Cooked	Stovetop boiled			Sysco$^{\text{TM}}$ Corp
Egg	Raw				Sysco$^{\text{TM}}$ Corp
Egg noodles	Cooked	Stovetop boiled	800 g water to 100 g noodles		Stop n Shop
Hot sauce, glass bottle	Shelf stable prepared	None			(Tabasco) McIlheny Co., Avery Island, LA. Sysco$^{\text{TM}}$ Corp
Popcorn	Pre-popped	None	None	None	Smartfood®
Mayonnaise, Hellman's	Shelf stable prepared	None			Sysco$^{\text{TM}}$ Corp
Mayonnaise, Hellman's fat-free	Shelf stable prepared	None			Sysco$^{\text{TM}}$ Corp
Pistachio nuts	Raw, shelled	None	None		Stop n Shop
Salsa, plastic bottle	Shelf stable, prepared	None			Casa Solana Sysco$^{\text{TM}}$ Corp

Table 3
Carotenoid concentrations in corn and corn products (μg/100 g) (mean of duplicate analysis).

	Lutein *trans*	Zeaxanthin *trans*	L/Z[*]	Lutein *cis*	Zeaxanthin *cis*	Cryptoxanthin	β-Carotene *trans*	β-Carotene *cis*	α-Carotene
Apple Jacks®, cereal	43	24	*1.8*	2	2	5	0	0	0
Cap'n Crunch®, cereal	42	20	*2.0*	4	4	3	0	0	0
Cheetos®	66	73	*0.9*	48	12	8	0	0	0
Chex Mix®	48	25	*1.9*	4	4	4	12	3	6
Corn, cooked from frozen	202	202	*1.0*	37	25	0	14	0	15
Corn Chex®, cereal	151	115	*1.3*	17	20	15	7	5	2
Corn Flakes, cereal	40	49	*0.8*	15	12	11		4	0
Corn Muffin	86	51	*1.7*	10	44	8	0	0	0
Corn Pops®, cereal	42	36	*1.2*	5	9	0	3	0	0
Cornmeal, yellow	001	531	*1.9*	63	25	46	29	0	0
Cornmeal, white	13	13	*1.0*	0	0	0	0	0	0
Crispix®, cereal	25	21	*1.2*	2	3	3	0	0	0
Fritos®	17	33	*0.5*	11	5	3	8	1	13
Frosted Flakes®, cereal	33	81	*0.4*	13	16	9	4	6	2
Fruit Loops®, cereal[a]	41	24	*1.7*	4	4	4	0	0	0
Life®, cereal	51	25	*2.0*	3	3	3	5	0	0
Popcorn, Smartfood®[b]	64	141	*0.5*	59	83	24	17	0	0
Reese's Puffs®, cereal	46	34	*1.4*	7	9	5	0	0	0
Tortilla, corn	276	255	*1.1*	26	45	30	0	0	0
Tortilla chip, Tostidos®	0	0	–	0	0	0	0	0	0

[*] Ratio of all-*trans* lutein to all-*trans* zeaxanthin.

[a] Mean of four analyses.

[b] Mean of six analyses.

The lower limit of detection of our extraction and HPLC procedures is 0.2 pmol for carotenoids. Our laboratory has participated in the National Institute of Standards & Technology (NIST) Round-Robins and has a <5% variation for carotenoids. Our HPLC systems are calibrated with standard reference material (SRM) 968a—fat-soluble vitamins in human serum and plasma, provided by in NIST. To verify the precision of our analytical procedure, triplicates of stored plasma pool samples (stored at −80 °C) are extracted and assayed every few months. We find that our interassay CV for this pool ($n = 25$) was 4%; the intra-assay CV ($n = 9$) was 4%. Recovery of the internal standard averages 97%. The accuracy, determined by the recovery of added β-carotene to a plasma sample, averaged 95%. Recently, we participated in the analysis of the NIST Standard Reference Material 2385 Spinach and had a <5% variation for lutein, zeaxanthin, and β-carotene.

3. Results

Carotenoid concentrations in corn and corn products are shown in Table 3. For most foods, lutein was the predominant carotenoid, with the exceptions of Fritos®, Frosted Flakes®, and popcorn, in which zeaxanthin predominated. The lutein:zeaxanthin ranged from 0.5 to 2.0, with a mean value of 1.3. Lutein and zeaxanthin content in Cheetos®, cooked corn, Corn Chex®, corn flakes, white cornmeal, and Crispix® were comparable. Corn-based breakfast cereals contained very similar amounts of lutein (range: 25–52 μg/100 g) and zeaxanthin (range: 20–49 μg/100 g). The exceptions were relatively higher amounts of lutein in Corn Chex® and zeaxanthin in Corn Chex® and Frosted Flakes®. Corn tortilla contained relatively high amounts of lutein and zeaxanthin (274 and 255 μg/100 g, respectively), while tortilla chips contained non-detectable amounts of carotenoids. For all of the corn products, except corn meal, corn tortillas, and Corn Chex®, concentrations of xanthophylls were at least two-fold less than that found in cooked corn. Yellow cornmeal contained 1001 and 531 μg/100 g lutein and zeaxanthin, respectively, while white cornmeal contained negligible amounts. The contribution of *cis* xanthophyll isomers to the total in corn and corn products ranged from 0 to 41%. Other carotenoids found in these foods were cryptoxanthin, β-carotene and α-carotene, but concentrations were small.

Carotenoid concentrations in egg products and other selected foods are shown in Table 4. For most foods, zeaxanthin concentrations were much lower than those for corn and corn products, with the exception of whole egg and egg yolk with

Table 4
Carotenoid concentrations in egg products and selected foods (μg/100 g) (mean of duplicate analysis).

	Lutein *trans*	Zeaxanthin *trans*	L/Z[*]	Lutein *cis*	Zeaxanthin *cis*	Cryptoxanthin	β-Carotene *trans*	β-Carotene *cis*	α-Carotene
Bread, white	15	0	–	0	0	0	0	0	
Egg noodles, cooked	16	0	–	0	0	0	2	0	
Egg (yolk + white), cooked	237	216	*1.1*	36	36	0	0	0	0
Egg yolk, cooked	645	587	*1.1*	99	99	0	0	0	0
Egg (yolk + white), raw	288	279	*1.0*	48	40	0	0	0	0
Egg yolk, raw	787	762	*1.0*	130	108	0	0	0	0
Hot sauce	0	0	–	0	0	0	60	0	0
Macaroni and cheese, Kraft	3					15			
Mayonnaise, Hellman's®	35	21	*1.7*	6	6	0	0	0	0
Mayonnaise, Hellman's® fat free	5	3	*1.7*	0	1	0	21	1	4
Pistachio, shelled	1405	0	–	0	0	0	0	0	0
Salsa	40	0	–	21	0	0	144	0	0
Spinach noodles, cooked	176	0	–	0	0	0	21	0	0

[*] Ratio of all-*trans* lutein to all-*trans* zeaxanthin.

Table 5
Carotenoid concentrations in fruits and vegetables (μg/100 g) (mean of duplicate analysis).

	Lutein *trans*	Zeaxanthin *trans*	L/Z[*]	Lutein *cis*	Zeaxanthin *cis*	Cryptoxanthin	β-Carotene *trans*	β-Carotene *cis*	α-Carotene
Apple, red delicious with skin	15	0	–	0	0	0	18	6	0
Apricot, dried	0	0	–	0	0	51	2249	185	436
Artichoke heart	62	18	*3.4*	33	0	0	14	0	0
Asparagus, cooked	991	0	–	0	0	10	265	45	0
Broccoli, cooked	772	0	–	0	0	0	362	43	0
Brussel sprouts, cooked	155	0	–	0	0	4	218	42	0
Cabbage, red	0	0	–	0	0	0	0	0	0
Cantaloupe, raw	19	0	–	0	0	5	2063	25	60
Cilantro	7703	0	–	0	0	0	5531	933	0
Cucumber[a]	361	0	–	0	0	0	87	15	0
Endive	399	3	*133.0*	0	0	3	49	8	0
Grapes, green[a]	53	6	*8.8*	0	0	0	34	5	0
Grapes, red	24	4	*6.0*	0	0	0	18	0	0
Green beans, cooked from frozen	306	0	–	0	0	0	0	0	0
Honeydew	25	0	–	0	0	0	18	3	0
Kale, cooked	8884	0		–	0	0	0	4693	870
Kiwi	171	0		–	0	0	0	31	4
Lettuce, iceberg	171	12	*14.3*	0	0	172	0	0	0
Lettuce, romaine	3824	0	–	0	0	0	2730	509	0
Lima beans, cooked	155	0	–	0	0	0	76	11	0
Mango	6	0	–	0	0	0	142	43	14
Nectarine	8	4	*2.0*	0	0	5	96	12	0
Olive, green	79	0	–	76	0	0	100	0	0
Orange juice	33	26	*1.3*	0	0	22	0	0	0
Parsley	4326	0	–	0	0	0	2264	317	0
Peach, canned	0	8	–	0	0	48	0	0	0
Peach, raw	11	3	*3.7*	0	0	0	141	24	0
Pepper, green	173	0	–	0	0	0	38	6	0
Pepper, orange	208	1665	0.1	0	0	136	926	98	98
Pepper, red	0	22	0.0	0	0	0	153	201	85
Pepper, yellow	139	18	7.7	0	0	0	38	11	17
Scallions, raw	782	0	–	0	0	4	370	62	0
Scallions, cooked in oil		2488	0	–	0	0	0	0	0
Spinach, cooked	12,640	0	–	864	0	0	8852	1280	0
Spinach, raw	6603	0	–	621	0	0	4388	708	0
Squash, acorn, raw no skin	47	0	–	0	0	0	224	16	0
Squash, butternut, cooked	57	0	–	0	0	0	569	38	183
Squash, yellow, cooked	150	0	–	0	0	0	116	0	0
Tomato, raw[b]	32	0	–	0	0	0	0	0	0
Watermelon	4	0	–	0	0	5	126	0	0
Zucchini, cooked with skin	1355	0	–	0	0	0	311	46	0

[*] Ratio of all-*trans* lutein to all-*trans* zeaxanthin.
[a] Mean of four analyses.
[b] Also contains 901 μg/100 g all-*trans* lycopene.

comparable amounts of lutein and zeaxanthin. Spinach noodles contained ~10 times more lutein than egg noodles and neither contained zeaxanthin. Regular mayonnaise contained seven times more xanthophylls than fat-free mayonnaise. Among these foods, pistachios were a major source of xanthophyll, containing 1405 μg/100 g lutein and no zeaxanthin. Other carotenoids found in these foods were cryptoxanthin, β-carotene and α-carotene, but concentrations were small.

Carotenoid concentrations in commonly consumed fruits and vegetables are shown in Table 5. Among these, the green leafy vegetables were the richest sources of lutein but contained small or no amounts of zeaxanthin. Compared to raw spinach, cooked spinach contained considerably more carotenoids (*trans* lutein and β-carotene). However, *cis* lutein only slightly increased after cooking. These increases may reflect water losses during cooking. The relatively smaller increase for *cis* lutein may be due to losses of this carotenoid during cooking. Only artichoke hearts, green olives and spinach contained *cis* isomers of xanthophylls. Other carotenoids found in these foods were cryptoxanthin and α-carotene, but concentrations were small. The green leafy vegetables, apricots, and cantaloupe contained significant amounts of β-carotene with the green leafy vegetables containing the highest levels. Of note is that for all the fruits and vegetables, lutein was the predominate xanthophyll. The exception was orange pepper, containing eight times more zeaxanthin than lutein. Further, when present, β-carotene predominated in the *trans* form in all foods analyzed. In general, for the fruits and vegetables with previously published β-carotene data our results were comparable (USDA, 1998). Individual data for lutein and zeaxanthin are more limited for the foods selected for this study. However for those foods common to our study and previous reports (USDA, 1998), when lutein and zeaxanthin concentrations are combined, our data are comparable.

Of all the foods selected, lycopene was measured only in tomatoes (Table 3).

4. Discussion

In our analysis, corn and corn products were major sources of dietary zeaxanthin, while green leafy vegetables were major sources of dietary lutein. This may have implications when considering differences in xanthophylls intake among various ethnicities. For example, major dietary sources of xanthophylls for elder Hispanics are corn and corn products whereas non-Hispanic whites obtain important amounts of these xanthophylls from leafy green vegetables (spinach, broccoli) (Bermudez et al., 2005).

Egg products were relatively poor sources of xanthophylls, even when considering that the xanthophyll bioavailability may be greater than that in fruits and vegetables (Chung et al., 2004). The exception is egg yolk in which the total xanthophyll content is ~1.2 mg/100 g. Given that the bioavailability is ~3 times greater than that from a vegetable source (Chung et al., 2004) one egg yolk could provide approximately 14% of the recommended daily intake of 6 mg (Seddon et al., 1994).

It should be noted, however, that approximately 50 g of cooked spinach would provide 100% of the recommendation.

In all foods, the *trans* xanthophylls predominated over the *cis* form, although processed foods, e.g., breakfast cereals contained more *cis* isomers than fruits and vegetables. This is likely due to isomerization during food processing. The predominant isomeric form of xanthophylls in the retina is the *trans*, with little or no *cis* isomer (Johnson et al., 2005), suggesting that this may be the isomeric form that is important in retinal health. Furthermore, the *trans* and *cis* forms of β-carotene and lycopene appear to have differing bioavailabilities in humans (Gaziano et al., 1995; Johnson et al., 1996; Stahl and Sies, 1992; Unlu et al., 2007). Little research has been conducted on the bioavailability of isomers of other carotenoids. Therefore, in the quantitation of xanthophylls in foods it may be important to consider contributions from the *trans* and *cis* forms. With the exception of the work by Humphries and Khachik (2003), it is not clear if isomeric forms are little considered in dietary databases.

With the exception of tomatoes, none of the foods analyzed contained lycopene, a major dietary carotenoid. This was because of the method used to select foods. That is, the major contributors to xanthophyll intake in the U.S. diet were used for analysis. Foods selected with these criteria contained no lycopene.

It must be noted that there are limitations to this study. There are many factors that will influence lutein and zeaxanthin content of fruits, vegetables and food products, including ripening, cooking preparation, and time of harvesting (Lessin et al., 1997; Torregrosa et al., 2005). Further, foods were purchased from local grocers and may differ in lutein and zeaxanthin content from one provider to another. This may be less of an issue for the mass produces food products we analyzed, e.g. breakfast cereals and salty snacks. Despite this limitation, for those foods common to our study and the USDA database, values for lutein plus zeaxanthin are comparable (USDA, 1998). It should be noted that few foods in this study are found in the USDA database. For the corn products, only corn and yellow cornmeal are common (Table 3). For egg products and selected foods, only raw eggs are common (Table 4). For fruits and vegetables, 11 of the 20 fine foods are found in the USDA database (Table 5).

Another limitation to this study is that foods were selected based on their contribution to lutein and zeaxanthin intakes in a U.S. population. These foods are likely to differ among other countries. For example, in NHANES 2001–2002, the major contributors to lutein + zeaxanthin intake were green leafy vegetables followed by orange juice, eggs, and corn. In European diets, spinach, peas, broccoli, and lettuce are the major foods contributing to lutein + zeaxanthin intake (Granado et al., 2003; O'Neil et al., 2001). In a Spanish diet beets were a major source of dietary lutein followed by spinach, potato, lettuce and green beans whereas oranges and potato were the major dietary sources of zeaxanthin (Granado et al., 1996). Of the fruits and vegetables common to the UK diet, cabbage, watercress and spinach are the major sources of lutein and orange pepper and sweet corn were found to be major sources of zeaxanthin (Hart and Scott, 1995).

5. Conclusions

The current dietary databases make it difficult to assess the relative roles of lutein and zeaxanthin in eye health. This is because lutein and zeaxanthin content are reported together. Also, there is very limited data on processed foods. The data from this study will provide added information to the current database for lutein and zeaxanthin content of commonly consumed foods as well as enhance the validity of estimates of dietary intake of these xanthophylls and their respective contribution to health.

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References

Bermudez, O.I., Ribaya-Mercado, J.D., Talegawkar, S.A., Tucker, K.L., 2005. Hispanic and non-Hispanic white elders form Massachusetts have different patterns of carotenoid intake and plasma concentrations. J. Nutr. 135, 1496–1502.

Bone, R.A., Landrum, J.T., 1992. Distribution of macular pigment components, zeaxanthin and lutein, in human retina. In: Packer, L. (Ed.), Methods in Enzymology. Academic Press, San Diego, pp. 360–366.

Bone, R.A., Landrum, J.T., Tarsis, S.E., 1985. Preliminary identification of the human macular pigment. Vision Res. 25, 1531–1535.

Chung, H.Y., Rasmussen, H., Johnson, E.J., 2004. Lutein bioavailability is higher from lutein-enriched eggs than from supplements and spinach in men. J. Nutr. 134, 1857–1893.

Food Surveys Research and Group, 2006. We Are What We Eat in America, NHANES 2001–2002. Food Surveys Research Group. U.S. Dept. of Agriculture, Agricultural Research Service.

Gaziano, J.M., Johnson, E.J., Russell, R.M., Manson, J.M., Stampfer, M.J., Ridker, P.M., Frei, B., Hennekens, C.H., Krinsky, N.I., 1995. Discrimination in absorption or transport of β-carotene isomers following oral supplementation with either all-*trans*- or 9-*cis*-β-carotene. Am. J. Clin. Nutr. 61, 1248–1252.

Granado, F., Olmedilla, B., Blanco, I., 2003. Nutritional and clinical relevance of lutein in human health. Br. J. Nutr. 90, 487–502.

Granado, F., Olmedilla, B., Blanco, I., Rojas-Hidalgo, E., 1996. Major fruit and vegetable contributors to the main serum carotenoids in the Spanish diet. Eur. J. Clin. Nutr. 50, 246–250.

Hart, D.J., Scott, K.J., 1995. Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. Food Chem. 54, 101–111.

Humphries, J.M., Khachik, F., 2003. Distribution of lutein, zeaxanthin and related geometrical isomers of fruit, vegetables, wheat and pasta products. J. Agric. Food Chem. 51, 1322–1327.

Johnson, E.J., Krinsky, N.I., Russell, R.M., 1996. Serum response of all-*trans* and 9-*cis* isomers of β-carotene in humans. J. Am. Coll. Nutr. 15, 620–624.

Johnson, E.J., Neuringer, M., Russell, R.M., Schalch, W., Snodderly, D.M., 2005. Nutritional manipulation of primate retinas. III. Effects of lutein or zeaxanthin supplementation on adipose and retina of xanthophylls-free monkeys. Invest. Ophthalmol. Vis. Sci. 46, 692–702.

Lessin, W.J., Catigani, G.L., Schwartz, S.J., 1997. Quantification of *cis-trans* isomers of provitamin A carotenoids in fresh and processed fruits and vegetables. J. Agric. Food Chem. 45, 3728–3732.

O'Neil, M.E., Carroll, Y., Corridan, B., Olmedilla, B., Granado, F., Blanco, I., Van den Berg, H., Hininger, I., Rousell, A.M., Chopra, M., Southon, S., Thurnhan, D.I., 2001. A European carotenoid database to assess carotenoid intakes and its use in a five-country comparative study. Br. J. Nutr. 85, 499–507.

Riso, P., Porrini, M., 1997. Determination of carotenoids in vegetable foods and plasma. Int. J. Vitam. Nutr. Res. 67, 47–54.

Seddon, J.M., Ajani, U.A., Sperduto, R.D., Hiller, R., Blair, N., Burton, T.C., Farber, M.D., Gragoudas, E.S., Haller, J., Miller, D.T., Yannuzzi, L.A., Willett, W., 1994. Dietary carotenoids, vitamins A, C, and E, and advanced age-related macular degeneration. Eye Disease Case–Control Study Group. JAMA 272, 1413–1420.

Snodderly, D.M., 1995. Evidence for protection against age-related macular degeneration by carotenoids and antioxidant vitamins. Am. J. Clin. Nutr. 62, 1448S–1461S.

Sommerburg, O., Keunen, J.E., Bird, A.C., van Kuijk, F.J., 1998. Fruits and vegetables that are sources for lutein and zeaxanthin: the macular pigment in human eyes. Br. J. Ophthalmol. 82, 907–910.

Stahl, W., Sies, H., 1992. Uptake of lycopene and its geometrical isomers is greater from heat-processed than from unprocessed tomato juice in humans. J. Nutr. 122, 2161–2166.

Torregrosa, F.C., Cortes, M.J., Esteve, F.A., 2005. Effect of high-intensity pulsed electric fields processing and conventional heat treatment on orange–carrot juice carotenoids. J. Agric. Food Chem. 53, 9519–9525.

Unlu, N.Z., Bohn, T., Francis, D.M., Nagaraja, H.N., Clinton, S.K., Schwartz, S.J., 2007. Lycopene from heat-induced *cis*-isomer-rich tomato sauce is more bioavailable than from all-*trans*-rich tomato sauce in human subjects. Br. J. Nutr. 98, 140–146.

USDA, 1998. USDA-NCC Carotenoid Database for U.S. Foods-1998.

West, C.E., Poorvliet, E.J., 1993. The Carotenoid Content of Foods With Special Reference to Developing Countries. U.S. Agency for International Development, Washington, DC.