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). 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.
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/browning 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.

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 (~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 × 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 × 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, cryptoxanthin, α-carotene, all-trans-β-carotene, 9- and 13-cis-β-carotene, 5-, 9-, 13-, and 15-cis- and trans-lutein 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 Nutritional). 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 1

<table>
<thead>
<tr>
<th>Common food</th>
<th>Scientific name</th>
</tr>
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<tbody>
<tr>
<td>Apple, red delicious</td>
<td>Malus domestica</td>
</tr>
<tr>
<td>Apricot, dried</td>
<td>Prunus armeniaca</td>
</tr>
<tr>
<td>Artichoke, globe (heart)</td>
<td>Cynara acanthus</td>
</tr>
<tr>
<td>Asparagus, cooked</td>
<td>Asparagus officinalis</td>
</tr>
<tr>
<td>Broccoli, cooked (flowers and stems)</td>
<td>Brassica oleracea var. italica</td>
</tr>
<tr>
<td>Brussel sprouts, cooked (from frozen)</td>
<td>Brassica oleracea var. gemmifera</td>
</tr>
<tr>
<td>Cabbage, red</td>
<td>Brassica oleracea var. capitata</td>
</tr>
<tr>
<td>Cantaloupe, raw</td>
<td>Cucumis melo</td>
</tr>
<tr>
<td>Cilantro (Chinese parsley)</td>
<td>Coriander sativus</td>
</tr>
<tr>
<td>Cucumber</td>
<td>Cucumis sativus</td>
</tr>
<tr>
<td>Endive</td>
<td>Cichorium endivia</td>
</tr>
<tr>
<td>Grapes, green</td>
<td>Vitis vinifera</td>
</tr>
<tr>
<td>Grapes, red</td>
<td>Vitis vinifera</td>
</tr>
<tr>
<td>Green beans, cooked from frozen</td>
<td>Phaseolus vulgaris</td>
</tr>
<tr>
<td>Honeydew</td>
<td>Cucumis melo</td>
</tr>
<tr>
<td>Kale, cooked</td>
<td>Brassica oleracea var. acephala</td>
</tr>
<tr>
<td>Kiwi (Kiwifruit, Chinese gooseberry)</td>
<td>Actinidia chinensis</td>
</tr>
<tr>
<td>Lettuce, iceberg</td>
<td>Lactuca sativa (crisphead)</td>
</tr>
<tr>
<td>Lettuce, romaine</td>
<td>Lactuca sativa (Cos)</td>
</tr>
<tr>
<td>Lima beans, cooked</td>
<td>Phaseolus lunatus</td>
</tr>
<tr>
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<td>Mangifera indica</td>
</tr>
<tr>
<td>Nectarine</td>
<td>Prunus persica</td>
</tr>
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<td>Olea europea</td>
</tr>
<tr>
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<td>Citrus sinensis (juice of)</td>
</tr>
<tr>
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<td>Petroselinum crispum</td>
</tr>
<tr>
<td>Peach, canned</td>
<td>Prunus persica</td>
</tr>
<tr>
<td>Peach, raw</td>
<td>Prunus persica</td>
</tr>
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<tr>
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<td>Capsicum annum</td>
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<tr>
<td>Pepper, red (Bell)</td>
<td>Capsicum annum</td>
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<td>Pepper, yellow (Bell)</td>
<td>Capsicum annum</td>
</tr>
<tr>
<td>Scallions, cooked in oil</td>
<td>Allium cepa</td>
</tr>
<tr>
<td>Scallions, cooked in oil</td>
<td>Allium cepa</td>
</tr>
<tr>
<td>Spinach, cooked</td>
<td>Spinacia oleracea</td>
</tr>
<tr>
<td>Spinach, raw</td>
<td>Spinacia oleracea</td>
</tr>
<tr>
<td>Squash, acorn, cooked</td>
<td>Cucurbita moschata; c maxima</td>
</tr>
<tr>
<td>Squash butternut, cooked</td>
<td>Cucurbita moschata; c maxima</td>
</tr>
<tr>
<td>Squash, yellow, cooked</td>
<td>Cucurbita pepo</td>
</tr>
<tr>
<td>Watermelon</td>
<td>Citrullus vulgaris</td>
</tr>
<tr>
<td>Zucchini, cooked</td>
<td>Cucurbita pepo</td>
</tr>
<tr>
<td>Food</td>
<td>Form</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----------------------</td>
</tr>
<tr>
<td><strong>Fruits</strong></td>
<td></td>
</tr>
<tr>
<td>Artichoke</td>
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</tr>
<tr>
<td>Asparagus</td>
<td>Frozen</td>
</tr>
<tr>
<td>Broccoli</td>
<td>Frozen, stems and flowers</td>
</tr>
<tr>
<td>Brussel sprouts</td>
<td>Frozen</td>
</tr>
<tr>
<td>Butternut squash</td>
<td>Frozen, peeled, cubed</td>
</tr>
<tr>
<td>Cabbage, red</td>
<td>Raw, leaves</td>
</tr>
<tr>
<td>Spinach</td>
<td>Frozen</td>
</tr>
<tr>
<td>Carrots</td>
<td>Frozen, peeled rounds</td>
</tr>
<tr>
<td>Carrots</td>
<td>Raw, peeled rounds</td>
</tr>
<tr>
<td>Corn</td>
<td>Frozen, off cob</td>
</tr>
<tr>
<td>Cucumber</td>
<td>Raw, sliced</td>
</tr>
<tr>
<td>Endive</td>
<td>Raw leaves</td>
</tr>
<tr>
<td>Green beans</td>
<td>Frozen, cut</td>
</tr>
<tr>
<td>Kale</td>
<td>Fresh, chopped leaves</td>
</tr>
<tr>
<td>Lettuce, iceberg</td>
<td>Raw leaves</td>
</tr>
<tr>
<td>Lime beans</td>
<td>Canned, drained</td>
</tr>
<tr>
<td>Okra</td>
<td>Frozen, sliced</td>
</tr>
<tr>
<td>Peas</td>
<td>Frozen</td>
</tr>
<tr>
<td>Pepper, green</td>
<td>Raw, chopped</td>
</tr>
<tr>
<td>Pepper, orange</td>
<td>Raw, chopped</td>
</tr>
<tr>
<td>Pepper, red</td>
<td>Raw, chopped</td>
</tr>
<tr>
<td>Pepper, yellow</td>
<td>Raw, chopped</td>
</tr>
<tr>
<td>Scallions</td>
<td>Fresh, chopped</td>
</tr>
<tr>
<td>Scallions</td>
<td>Raw, chopped</td>
</tr>
<tr>
<td>Spinach</td>
<td>Frozen</td>
</tr>
<tr>
<td>Spinach</td>
<td>Raw leaves</td>
</tr>
<tr>
<td>Squash, acorn</td>
<td>Raw, peeled, cubed</td>
</tr>
<tr>
<td>Squash, zucchini</td>
<td>Frozen, sliced with skin</td>
</tr>
<tr>
<td>Squash, yellow (summer)</td>
<td>Frozen, sliced, with skin</td>
</tr>
<tr>
<td><strong>Herbs</strong></td>
<td></td>
</tr>
<tr>
<td>Cilantro</td>
<td>Raw, sprigs, no stems</td>
</tr>
<tr>
<td>Curly Parsley</td>
<td>Raw, sprigs, no stems</td>
</tr>
<tr>
<td><strong>Fruits</strong></td>
<td></td>
</tr>
<tr>
<td>Apple, red delicious</td>
<td>Raw, with skin</td>
</tr>
<tr>
<td>Apricot</td>
<td>Dried</td>
</tr>
<tr>
<td>Cantaloupe</td>
<td>Raw</td>
</tr>
<tr>
<td>Grapes, green</td>
<td>Raw</td>
</tr>
<tr>
<td>Grapes, red</td>
<td>Raw</td>
</tr>
<tr>
<td>Honeydew melon</td>
<td>Raw</td>
</tr>
<tr>
<td>Kiwi</td>
<td>Raw, peeled</td>
</tr>
<tr>
<td>Mango</td>
<td>Raw, peeled</td>
</tr>
<tr>
<td>Nectarine</td>
<td>Raw, peeled sections</td>
</tr>
<tr>
<td>Olive, green (Pitted manzanilla)</td>
<td>Bottled in brine</td>
</tr>
<tr>
<td>Orange juice, 100% juice</td>
<td>Made from concentrate</td>
</tr>
<tr>
<td>Peach</td>
<td>Raw with peel</td>
</tr>
<tr>
<td>Peach, canned</td>
<td>Peeled, canned in own juice</td>
</tr>
<tr>
<td>Pumpkin</td>
<td>Canned</td>
</tr>
<tr>
<td>Watermelon</td>
<td>Raw without rind</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>Bread, white sliced</td>
<td>Shelf stable, prepared</td>
</tr>
<tr>
<td>Cornmeal, yellow</td>
<td>Shelf stable uncooked</td>
</tr>
<tr>
<td>Cornmeal, white</td>
<td>Shelf stable uncooked</td>
</tr>
<tr>
<td>Corn muffin</td>
<td>Shelf stable, prepared</td>
</tr>
<tr>
<td>Spinach noodles</td>
<td>Cooked</td>
</tr>
<tr>
<td>Egg</td>
<td>Cooked</td>
</tr>
<tr>
<td>Egg noodles</td>
<td>Cooked</td>
</tr>
<tr>
<td>Hot sauce, glass bottle</td>
<td>Shelf stable prepared</td>
</tr>
<tr>
<td>Popcorn</td>
<td>Pre-popped</td>
</tr>
<tr>
<td>Mayonnaise, Hellman’s</td>
<td>Shelf stable prepared</td>
</tr>
<tr>
<td>Mayonnaise, Hellman’s fat-free</td>
<td>Shelf stable prepared</td>
</tr>
<tr>
<td>Pistachio nuts</td>
<td>Raw, shelled</td>
</tr>
<tr>
<td>Salsa, plastic bottle</td>
<td>Shelf stable, prepared</td>
</tr>
</tbody>
</table>
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 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 was 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 cryptocyanin, 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 some notable exceptions for the specific carotenoids mentioned.

### Table 3

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

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

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

### Table 4

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

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

* Ratio of all-trans lutein to all-trans zeaxanthin.
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 predominant 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 *cis* 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 foods, 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’Neill 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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