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Carotenoid concentrations in vegetables and fruits common to the Costa Rican diet

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The intake of vegetables and fruits has been shown to reduce the risk of multiple diseases in many different populations. Various components of these foods have been investigated to explain the protective effects. Carotenoids, a class of phytochemicals found in these foods, have been investigated for links between their oxidative, provitamin A, and cellular properties and disease risk reduction. Many nutrition-based studies employ dietary questionnaires to estimate intakes for associations with disease. Reliable assessments of the components of these foods are necessary for accurate quantification of intake. While databases have been published, they vary greatly due to differences in methodology, growth conditions, and handling. In addition, data relevant to foods grown and consumed in Latin America and Costa Rica are scarce. In this paper, we employ a quality-controlled method for analyzing foods to obtain data on vegetables and fruits that are common to the Costa Rican diet. The data is presented in tables and compared to databases from the United States and Europe.

Introduction

Vegetables and fruits have long been associated with good health. From the first federal guidelines in the United States published more than 50 years ago, the importance of their consumption has been stressed again and again (Rimm, 2002). The accumulated evidence of over 200 studies examining the relationship between fruit and vegetable intake and cancer in various populations suggests that these foods reduce the risk of numerous forms of the disease, including cancers of the mouth, throat, lung, stomach, bladder, colon, rectum, breast, and prostate (van Poppel & Goldbohm, 1995; Gann *et al*., 1999; Willett, 2001). Other research shows that vegetable and fruit consumption is protective against some forms of heart disease (Kohlmeier & Hastings, 1995; Joshipura *et al*., 2001; Willett, 2001; Rimm, 2002) and stroke (Joshipura *et al*., 1999; Willett, 2001), possibly through the reduction of oxidized low-density lipoprotein cholesterol (Southon, 2001). Reduced risks of degenerative eye diseases (Snodderly, 1995; Willett, 2001) and Alzheimer disease (Engelhart *et al*., 2002) have also been shown with increased

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intake. Numerous phytochemicals present in vegetables and fruits that have biologically plausible roles in reducing the risk of disease have been investigated. Probably the most frequently studied of these compounds are the carotenoids, pigments produced by non-animal species that are present to varying degrees in most of the fruits and vegetables we eat. Because these pigments are not manufactured by humans, their presence in the body is based solely on consumption, and tissue levels are controlled by absorption and internal storage mechanisms. The biological structure of this class of biomolecules makes them powerful antioxidants, which may play a role in protecting the body from numerous diseases that are associated with oxidative stresses and damage (Handelman, 2001; Willett, 2001). Carotenoids also have many non-antioxidant properties that affect cellular signaling pathways, modify the expression of some genes, and can act as inhibitors of regulatory enzymes, which may play a part in disease prevention (Stahl *et al*., 2002). In addition, some of these compounds may be broken down in the body to vitamin A (Retinol) (Handelman, 2001; Willett, 2001), which aids vision and may prevent normal cells from becoming cancerous (Willett, 2001). Research on the effects of carotenoids on the body has been two-sided, with null and negative associations, as well (Alpha-Tocopherol, Beta Carotene Cancer Prevention Study Group, 1994; Hennekens *et al*., 1996).

Many studies relating food intakes with disease employ dietary questionnaires to measure the intake of various whole foods (Ritenbaugh *et al*., 1996; Michaud *et al*., 1998). After an overall picture of the diet is obtained, it is possible to extrapolate the overall intake of nutrients and chemicals without exact physical measurements. To do this, it is important to have accurate information on the nutrient and chemical composition of each food. Carotenoid databases have been published for European and North American populations (Chug-Ahuja *et al*., 1993; Mangels *et al*., 1993). But due to the natural heterogeneity of foods and variability between the methods by which they are analyzed, these databases are highly varied in their results. It is important to have data that accurately reflect the nutrient values of foods consumed in other parts of the world. Not only do food patterns differ markedly among nations and cultures, as shown in a five-country comparative study by O'Neill *et al*. (2001), but the food compositions themselves differ as well. For example, carrots in the United States tend to be significantly more orange (due to higher levels of β-carotene) than their European counterparts, reflective of regional preferences. These differences translate into marked variations in nutrient intake. In order to provide a reliable general database covering foods consumed in the tropics, we analyzed foods common to the Costa Rican diet for various carotenoids. To do this, we have analyzed the majority of foods in triplicate, using a different source for each replicate sample (e.g. supermarket, farmer's market, and home garden). This will help to take into consideration 'batch to batch' variation inherent in produce and to reduce the risk of publication of erroneous data obtained by measurement of a single sample that could have unusually high or low levels of our analytes. All analyses were performed with a quality-controlled laboratory procedure to ensure accuracy.

Material and methods

Foods commonly consumed in Costa Rica were collected within the greater San Jose area. Except where otherwise noted, each specific food was obtained from three different sources (such as the supermarket, farmer's market, or home garden) to account for variation in nutrient concentration due to factors such as growing conditions, ripeness at harvest, transportation and storage conditions, and ripeness at point-of-sale. The samples were prepared as they are eaten in a typical Costa Rican diet (cooked or raw), then frozen at $-20°C$ and shipped to the Harvard School of Public Health's Biomarker Analysis Laboratory for short-term storage, also at $-20°C$. In general, individual samples were analyzed once and triplicates were averaged into a mean value for each food. However, two foods had two samples analyzed (raw cilantro and banana) and two foods had only one sample analyzed (peaches and black beans).

The method established to analyze these foods is a modified version of a pre-existing method for analyzing human adipose tissue (El-Sohemy *et al*., 2002). Each sample was weighed by analytical balance into a test tube at appropriate sample masses estimated using the carotenoid concentrations in foods from the United States Department of Agriculture (USDA) Carotenoid Database. If results were unsatisfactory due to the mass of food used, analyses were repeated with adjusted food masses to optimize peak areas in order to obtain the best simultaneous measurement of each carotenoid for each food. Seven hundred and fifty microliters of 20% w/v aqueous ascorbic acid solution and 250 μl laboratory internal standard (10 μg/ml trans-β-apo-8′-carotenal in ethanol) were added. After weighing, solid foods were then ground within their test tube with a Polytron PT1200 homogenizer (VWR Scientific Products Bridgeport, NJ, USA) for a few seconds until sufficiently homogenized. The homogenizer tip was rinsed in 1000 μl absolute ethanol to retrieve adherent sample and the rinse was added to the homogenate. This solution was then saponified with 2000 μl of 60% w/v aqueous potassium hydroxide solution for 15 min in a 45°C water bath. Following saponification, each sample was extracted with 2000 μl hexane. The samples were vortexed for 3 min, centrifuged at 1240 × *g* for 4 min, and the organic hexane layer was decanted into an evaporating tube. This procedure was repeated and the second hexane extract was combined with that from the first. The hexane was then evaporated to dryness with a stream of nitrogen gas. The remaining residue was reconstituted with 100 ml of a 50:50 ethanol:dioxane mixture and 150 ml acetonitrile. The relatively extreme conditions required for saponification of food samples raised concerns that carotenoid levels may have been artificially reduced through degradation or oxidation (Schweigert *et al*., 2000; Breithaupt & Bamedi, 2001). All foods except those with high lipid content were extracted without saponification. These unsaponified foods showed no difference in mean carotenoid levels or in between-sample variation that would have been attributable to saponification. Therefore, both the saponified and unsaponified data were combined. The final solutions were quantitated by high-performance liquid chromatography on a Restek Ultra C18 150 mm × 4.6 mm column (Bellefon, PA, USA), with 3 μm particle size encased in a water bath to prevent temperature fluctuations, and equipped with a trident guard cartridge system (Restek Corp., Bellefonte, PA, USA). A mixture of acetonitrile, tetrahydrofuran, methanol, and a 1% ammonium acetate solution (68:22:7:3) (VWR International, West Chester, PA, USA) was used as the mobile phase. A constant flow rate of 1.1 ml/min was achieved using a Hitachi L-7100 pump in isocratic mode connected to an L-4250 UV/Vis (445 nm) detector, and a programmable AS-4000 autosampler with water-chilled tray, interfaced with a D-6000 interface module. Hitachi System Manager software (D-7000, version 3.0) was used for peak integration and data acquisition (Hitachi, San Jose, CA, USA). Internal laboratory plasma controls were included with each run and yielded overall coefficients of variations for each analyte as follows: lutein + zeaxanthin (Indofine Chemical, Hillsborough, NJ, USA), 4.4%; β-cryptoxanthin (Indofine Chemical), 4.3%; total lycopene (Sigma-Aldrich, St Louis, MO, USA), 5.5%; α-carotene (DHI, Horsholm, Denmark), 3.9%; and total β-carotene (Sigma-Aldrich), 4.0%.

Results and discussion

We have obtained measurements of the carotenoid content of various foods found in the Costa Rican diet. The results of our analysis are presented in Tables 1–4 as means for each food. This new database provides information on foods that had been unavailable until now. Many of these foods proved to be significant sources of carotenoids for the populations that consume them. These data will be of particular interest for studies on Latin American populations requiring dietary information, but are also useful in complementing existing databases for

Table 1. α-Carotene in Costa Rican fruits and vegetables (μg/100 g food) with published values from the United States and Europe

		Costa Rica			
English name	*Latin name*	*Mean*	*Standard deviation*	*United States*	*Europe*
Apple	*Malus sylvestris*	–	–	–	30.0
Avocado	*Persea americana*	76.0	45.8	28.0	17.0
Banana	*Musa balbisiana*	84.5	74.7	5.0	42.0
Beet, root	*Beta vulgaris*	–	–		0.0
Black beans	*Phseolus vulgaris*	–	–		
Broccoli, cooked	*Brassica oleracea italica*	24.4	19.8	1.0	
Cabbage, white raw	*Brassica oleracea capitata*	–	–		16.0
Carrot	*Daucus carota*				
Cooked		2385.3	1956.7	4109.0	3274.0
Raw		3863.2	831.3	4649.0	2186.0
Cassava, cooked	*Yucca schidigera*	–	–	0.0	
Cauliflower	*Brassica oleracea botrytis*	–	–		
Celery	*Apium graveolens*				
Leaves and stalk cooked		167.9	94.1		
Stalk cooked				0.0	
Cilantro	*Coriandrum sativum, leaves*				
Cooked		–	–		
Raw		–	–	72.0	
Corn, cooked	*Zea mays*	–	–		33.0
Cucumber	*Cucumis sativus*				
Without skin		–	–	8.0	
With skin					
Green beans, cooked	*Pisum sativa*	79.6	46.3		48.0
Jocote	*Spondias purpurea*	8.9	2.4		
Lime, sweet	*Citrus limon*	–	–		
Lettuce					
Local variety	*Lactuca sp.*	–	–		
Iceberg	*Lactuca americana*	–	–	2.0	
Mango	*Magnifera indica*	19.4	16.4	17.0	
Marañon	*Anacardium occidentale*	109.3	15.2		
Melon, cantaloupe	*Cucumis melo reticulatis*	44.1	21.6	27.0	
Mustard greens, cooked	*Brassica hirta*	4.2	3.3		
Nispero	*Symplocos lanata*	–	–		
Onion	*Allium sepa*		–	–	
Orange	*Citrus sinensis*	23.1	14.2	16.0	16.0
Orange juice	*Citrus sinensis, juice*	3.8	2.9	2.0	6.0
Papaya	*Carica papaya*	12.5	11.2	0.0	
Peaches, canned	*Prunus persica*	8.6	n/a	0.0	3.0
Peas	*Pisum sativa*	–	–	0.0	0.0
Pejibaye	*Bactris gasipaes*	4.2	1.8		
Pineapple	*Ananas comosus*	–	–		1.0
Plantain	*Musa acuminata*				
Green cooked		342.8	71.1		
Ripe cooked		116.4	46.5		
Potato	*Solanum tuberosum*	–	–		
Red sweet pepper	*Capsicum annuum*				
Cooked		107.1	54.7	62.0	
Raw		95.4	49.9	59.0	
Spinach, cooked	*Spinacia oleraceae*	–	–	0.0	
Squash					
Ayote cooked	*Cucurbita maxima*	96.7	35.2		
Chayote cooked	*Cucurbita pepo*	–	–		
Sweet potato	*Ipomoea batatas*	–			
Tangerine	*Citrus reticulata*	108.69	63.4	14.0	16.0
Tomato	*Lycoperiscon esculentum*				
Raw		–	–	112.0	
Ketchup		10.9	3.1		
Watermelon	*Citrullus vulgaris*	–	–	0.0	0.0

–, concentrations of the final liquid extract below the reliable detection limit of 7.74 μg/l for α-carotene.
Means for Costa Rican samples were from at least three replicate samples, except for banana ($n = 2$), black beans ($n = 1$), raw cilantro ($n = 2$), and peaches ($n = 1$). US data obtained from the USDA Carotenoid Database (Holden *et al*., 1999). European data obtained from O'Neill *et al*. (2001).
Blanks indicate data not available.

Table 2. β-Carotene isomers in Costa Rican fruits and vegetables (μg/100 g food) with published values from the United States and Europe

		Costa Rica				*United States*	*Europe*
				Total β-carotene			
English name	*Latin name*	*Trans-β-carotene (mean)*	*Cis-β-carotene (mean)*	*Mean*	*Standard deviation*	*Total β-carotene*	*Total β-carotene*
Apple	*Malus sylvestris*	27.7	–	31.6	12.7	22.0	
Avocado	*Persea americana*	139.2	60.1	199.3	141.9	53.0	43.0
Banana	*Musa balbisiana*	45.5	9.6	55.0	16.7	21.0	38.0
Beet, root	*Beta vulgaris*	–	–	–	–		0.0
Black beans	*Phseolus vulgaris*	–	–	–	–		
Broccoli, cooked	*Brassica oleracea italica*	2522.1	739.6	3261.7	2623.7	1042.0	944.0
Cabbage, white raw	*Brassica oleracea capitata*	–	7.1	7.1	9.9		16.0
Carrot	*Daucus carota*						
Cooked		4313.4	196.8	4510.1	3611.3	8015.0	9422.0
Raw		6919.3	168.1	7087.4	617.9	8836.0	7975.0
Cassava, cooked	*Yucca schidigera*	–	6.2	6.2	4.6	8.0	
Cauliflower	*Brassica oleracea botrytis*	–	–	–	–		9.0
Celery	*Apium graveolens*						
Leaves and stalk cooked		13848.7	2343.2	16191.9	7828.5		
Stalk cooked						210.0	1110.0
Cilantro	*Coriandrum sativum, leaves*						
Cooked		2811.8	639.6	3451.3	1456.8		
Raw		559.0	141.5	700.6	364.3	3440.0	
Corn, cooked	*Zea mays*	–	–	–	–		24.0
Cucumber	*Cucumis sativus*						
Without skin		–	–	–	–	31.0	
With skin						138.0	231.0
Green beans, cooked	*Pisum sativa*	370.8	105.6	476.3	312.8		247.0
Jocote	*Spondias purpurea*	82.1	21.7	103.8	43.4		
Lime, sweet	*Citrus limon*	–	–	–	–		0.0
Lettuce							
Local variety	*Lactuca sp.*	160.0	39.0	198.9	87.7		
Iceberg	*Lactuca americana*	153.4	39.4	192.1	173.0	192.0	71.0
Mango	*Magnifera indica*	762.4	75.5	838.0	694.2	445.0	1300.0
Marañon	*Anacardium occidentale*	792.4	142.8	935.2	243.3		
Melon, cantaloupe	*Cucumis melo reticulatis*	3442.4	161.4	3603.8	1388.5	1595.0	
Mustard greens, cooked	*Brassica hirta*	1703.4	426.6	2130.0	1467.4		
Nispero	*Symplocos lanata*	29.7	13.3	42.8	35.5		
Onion	*Allium sepa*	–	–	–	–		1.0
Orange	*Citrus sinensis*	29.2	12.5	41.8	26.0	51.0	25.0
Orange juice	*Citrus sinensis, juice*	27.7	7.7	35.4	46.0	4.0	82.0
Papaya	*Carica papaya*	330.4	27.5	357.9	206.9	276.0	

Table 2 (*Continued*)

		Costa Rica				*United States*	*Europe*
				Total β-carotene			
English name	*Latin name*	*Trans-β-carotene (mean)*	*Cis-β-carotene (mean)*	*Mean*	*Standard deviation*	*Total β-carotene*	*Total β-carotene*
Peaches, canned	*Prunus persica*	646.5	211.3	857.8	n/a	334.0	84.0
Peas	*Pisum sativa*	63.2	16.5	79.7	43.6	320.0	548.0
Pejibaye	*Bactris gasipaes*	59.1	34.1	93.2	36.1		
Pineapple	*Ananas comosus*	–	–	–	–	30.0	18.0
Plantain	*Musa acuminata*						
Green cooked		490.4	153.5	643.9	168.5		
Ripe cooked		107.7	84.1	191.9	61.8		
Potato	*Solanum tuberosum*	–	–	–	–	6.0	0.0
Red sweet pepper	*Capsicum annuum*						
Cooked		1940.6	590.5	2531.2	1594.8	2200.0	770.0
Raw		1474.8	338.9	1813.7	848.8	2379.0	480.0
Spinach, cooked	*Spinacia oleraceae*	493.9	312.8	806.7	43.7	5242.0	4489.0
Squash							
Ayote cooked	*Cucurbita maxima*	224.5	20.9	245.5	40.2		
Chayote cooked	*Cucurbita pepo*	–	–	–	–		
Sweet potato	*Ipomoea batatas*	376.4	119.6	496.1	1059.5	6220.0	
Tangerine	*Citrus reticulata*	459.6	60.6	520.2	327.7	71.0	152.0
Tomato	*Lycoperiscon esculentum*						
Raw		261.8	18.3	279.7	135.9	393.0	608.0
Ketchup		470.8	197.9	668.7	195.1	730.0	5000.0
Watermelon	*Citrullus vulgaris*	21.9	–	21.9	14.5	295.0	154.0

–, concentration of the final liquid extract below reliable detection limit of 7.31 μg/l for β-carotene.
Means for Costa Rican samples were from at least three replicate samples, except for banana ($n = 2$), black beans ($n = 1$), raw cilantro ($n = 2$), and peaches ($n = 1$). US data obtained from the USDA Carotenoid Database (Holden *et al*., 1999). European data obtained from O'Neill *et al*. (2001).
Blanks indicate data not available.

Table 3. Lycopene isomers in Costa Rican fruits and vegetables (µg/100 g f food) with published values from the United States and Europe

		Costa Rica				*United States*	*Europe*
				Total Lycopene			
English name	*Latin name*	*Trans-Lycopene (mean)*	*Cis-Lycopene (mean)*	*Mean*	*Standard deviation*	*Total Lycopene (mean)*	*Total Lycopene (mean)*
Apple	*Malus sylvestris*	–	–	–	–		
Avocado	*Persea americana*	–	29.0	29.0	18.9		
Banana	*Musa balbisiana*	–	–	–	–	0.0	
Beet, root	*Beta vulgaris*	–	–	–	–		0.0
Black beans	*Phseolus vulgaris*	–	–	–	–		
Broccoli, cooked	*Brassica oleracea italica*	–	89.4	89.4	71.1	0.0	
Cabbage, white raw	*Brassica oleracea capitata*	–	–	–	–		
Carrot	*Daucus carota*						
Cooked		–	85.4	86.4	70.3		
Raw		–	146.1	148.9	87.2		
Cassava, cooked	*Yucca schidigera*	–	–	–	–		
Cauliflower	*Brassica oleracea botrytis*	–	–	–	–		
Celery	*Apium graveolens*						
Leaves and stalk cooked		–	195.3	195.3	129.0		
Stalk cooked						0.0	
Cilantro	*Coriandrum sativum, leaves*						
Cooked		–	–	–	–		
Raw		–	–	–	–		
Corn, cooked	*Zea mays*	–	–	–	–		
Cucumber	*Cucumis sativus*						
Without skin		–	–	–	–		
With skin							
Green beans, cooked	*Pisum sativa*	–	–	–	–		
Jocote	*Spondias purpurea*	–	–	–	–		
Lime, sweet	*Citrus limon*	–	–	–	–		
Lettuce							
Local variety	*Lactuca sp.*	–	25.4	25.4	7.8		
Iceberg	*Lactuca americana*	–	24.1	24.1	22.8	0.0	
Mango	*Magnifera indica*	–	25.8	27.1	10.3		
Marañon	*Anacardium occidentale*	–	–	–	–		
Melon, cantaloupe	*Cucumis melo reticulatis*	–	61.9	61.9	26.6	0.0	
Mustard greens, cooked	*Brassica hirta*	–	–	–	–		
Nispero	*Symplocos lanata*	–	–	–	–		
Onion	*Allium sepa*	–	–	–	–		
Orange	*Citrus sinensis*	–	–	–	–	0.0	
Orange juice	*Citrus sinensis, juice*	–	–	–	–		
Papaya	*Carica papaya*	1037.7	–	1244.7	644.2	0.0	

Table 3 (*Continued*)

		Costa Rica				United States	Europe
				Total Lycopene			
English name	*Latin name*	*Trans-Lycopene (mean)*	*Cis-Lycopene (mean)*	*Mean*	*Standard deviation*	*Total Lycopene (mean)*	*Total Lycopene (mean)*
Peaches, canned	*Prunus persica*	13.6	33.7	47.3	n/a	0.0	
Peas	*Pisum sativa*	–	–	–	–	0.0	
Pejibaye	*Bactris gasipaes*	20.5	63.7	84.2	51.0		
Pineapple	*Ananas comosus*	–	–	–	–		
Plantain	*Musa acuminata*						
Green cooked		–	–	–	–		
Ripe cooked		–	–	–	–		
Potato	*Solanum tuberosum*	–	–	–	–		
Red sweet pepper	*Capsicum annuum*						
Cooked		–	77.5	77.5	36.1		
Raw		–	126.3	129.7	78.0		
Spinach, cooked	*Spinacia oleraceae*	–	–	–	–	0.0	
Squash							
Ayote cooked	*Cucurbita maxima*	–	32.3	32.3	18.3		
Chayote cooked	*Cucurbita pepo*	–	–	–	–		
Sweet potato	*Ipomoea batatas*	–	58.5	58.5	81.8		
Tangerine	*Citrus reticulata*	–	–	–	–	0.0	
Tomato	*Lycoperiscon esculentum*						
Raw		1155.2	109.7	1264.9	891.0	3025.0	2718.0
Ketchup		6990.6	604.7	7595.3	2703.1	17008.0	9900.0
Watermelon	*Citrullus vulgaris*	1604.2	–	1604.2	583.5	4868.0	3477.0

–, concentrations of the final liquid extract below the reliable detection limit of 8.49 μg/l for lycopene.
Means for Costa Rican samples were from at least three replicate samples, except for banana ($n = 2$), black beans ($n = 1$), raw cilantro ($n = 2$), and peaches ($n = 1$). US data obtained from the USDA Carotenoid Database (Holden *et al*., 1999). European data obtained from O'Neill *et al*. (2001).
Blanks indicate data not available.

Table 4. Xanthophyllic carotenoids in Costa Rican fruits and vegetables (µg/100 g food) with published values from the United States and Europe

		Costa Rica		*US*	*Europe*	*Costa Rica*		*United States*	*Europe*
		Lutein+zeaxanthin				*β-Cryptoxanthin*			
English name	*Latin name*	*Mean*	*Standard deviation*	*Lutein+ zeaxanthin (mean)*	*Lutein only (mean)*	*Mean*	*Standard deviation*	*β-Crypto- xanthin (mean)*	*β-Crypto- xanthin (mean)*
Apple	*Malus sylvestris*	21.1	4.9		51.0	14.3	5.5		10.0
Avocado	*Persea americana*	619.2	298.4		317.0	120.8	124.8	36.0	26.0
Banana	*Musa balbisiana*	57.4	18.2	0.0	22.0	–	–	0.0	
Beet, root	*Beta vulgaris*	8.8	3.9			–	–		
Black beans	*Phseolus vulgaris*	6.7	n/a			–	–		
Broccoli, cooked	*Brassica oleracea italica*	9005.1	8573.7	2445.0	1596.0	63.7	53.4	0.0	24.0
Cabbage, white raw	*Brassica oleracea capitata*	49.6	65.8		99.0	–	–		
Carrot	*Daucus carota*								
Cooked		297.5	207.1		252.0	–	–		
Raw		157.5	50.2		271.0	–	–		
Cassava, cooked	*Yucca schidigera*	–	–			–	–	0.0	
Cauliflower	*Brassica oleracea botrytis*	19.1	7.5		16.0	–	–		
Celery	*Apium graveolens*								
Leaves and stalk cooked		26351.4	14693.4			226.3	152.8		
Stalk cooked				250.0	163.0			0.0	
Cilantro	*Coriandrum sativum, leaves*								
Cooked		4976.4	1383.4			1126.1	981.0	404.0	
Raw		2575.8	774.4			2126.9	1214.4		
Corn, cooked	*Zea mays*	42.0	20.8	1800.0	819.0	–	–		
Cucumber	*Cucumis sativus*								
Without skin		51.1	37.9			–	–		
With skin					570.0				
Green beans, cooked	*Pisum sativa*	1162.8	585.5		492.0	19.4	6.4		
Jocote	*Spondias purpurea*	188.0	57.8			42.9	14.1		
Lime, sweet	*Citrus limon*	7.1	1.9		8.0	25.2	5.0		14.0
Lettuce									
Local variety	*Lactuca sp.*	1181.9	53.9	2635.0	1250.0	–	–	0.0	
Iceberg	*Lactuca americana*	2520.2	1354.9	352.0	167.0	–	–	0.0	
Mango	*Magnifera indica*	40.9	23.0			12.4	13.5	11.0	54.0
Marañon	*Anacardium occidentale*	56.0	14.1			136.7	65.0		
Melon, cantaloupe	*Cucumis melo reticulatis*	53.0	25.3	40.0		8.0	6.6	0.0	
Mustard greens, cooked	*Brassica hirta*	3324.5	966.7			35.0	14.5		
Nispero	*Symplocos lanata*	23.9	16.9			–	–		
Onion	*Allium sepa*	–	–		2.0	–	–		
Orange	*Citrus sinensis*	311.7	193.4	187.0	92.0	47.3	24.8	122.0	266.0

Table 4 (*Continued*)

		Costa Rica		US	Europe	Costa Rica		United States	Europe
		Lutein+zeaxanthin				β-Cryptoxanthin			
English name	*Latin name*	*Mean*	*Standard deviation*	*Lutein+ zeaxanthin (mean)*	*Lutein only (mean)*	*Mean*	*Standard deviation*	*β-Crypto-xanthin (mean)*	*β-Crypto-xanthin (mean)*
Orange juice	*Citrus sinensis, juice*	26.6	26.1	36.0	27.0	5.9	3.7	15.0	701.0
Papaya	*Carica papaya*	40.1	26.7	75.0		403.7	336.1	76.0	
Peaches, canned	*Prunus persica*	535.0	n/a	33.0	60.0	614.4	N/a	141.0	70.0
Peas	*Pisum sativa*	479.5	116.2	1350.0	1840.0	–	–	0.0	
Pejibaye	*Bactris gasipaes*	–	–			–	–		
Pineapple	*Ananas comosus*	–	–		2.0	–	–		2.0
Plantain	*Musa acuminata*								
Green cooked		35.1	2.4			–	–		
Ripe cooked		154.2	50.5			–	–		
Potato	*Solanum tuberosum*	22.3	4.1		6.0	–	–		
Red sweet pepper	*Capsicum annuum*								
Cooked		2724.0	1775.2		390.0	969.0	741.5		370.0
Raw		2463.7	1263.7		290.0	487.6	211.2	2205.0	250.0
Spinach, cooked	*Spinacia oleraceae*	4103.3	976.7	7043.0	6265.0	–	–	0.0	
Squash									
Ayote cooked	*Cucurbita maxima*	901.6	866.9			–	–		
Chayote cooked	*Cucurbita pepo*	40.0	67.9			–	–		
Sweet potato	*Ipomoea batatas*	27.1	2.6			14.9	7.4		
Tangerine	*Citrus reticulata*	325.7	132.0	243.0	106.0	830.1	384.9	485.0	1309.0
Tomato	*Lycoperiscon esculentum*								
Raw		130.8	57.9	130.0	77.0	–	–	0.0	
Ketchup		294.9	140.8		210.0	44.7	11.2		
Watermelon	*Citrullus vulgaris*	–	–	17.0	27.0	–	–	103.0	62.0

–, concentrations of the final liquid extract below the reliable detection limit of 6.31 µg/l for lutein+zeaxanthin and 5.51 µg/l β-cryptoxanthin.
Means for Costa Rican samples were from at least three replicate samples, except for banana ($n = 2$), black beans ($n = 1$), raw cilantro ($n = 2$), and peaches ($n = 1$). US data obtained from the USDA Carotenoid Database (Holden *et al*., 1999). European data obtained from O'Neill *et al*. (2001) — only provides data from lutein with no zeaxanthin data.
Blanks indicate data not available.

European countries and the United States. Data from the US Department of Agriculture's Carotenoid Database (Holden *et al*., 1999) and a European carotenoid database (O'Neill *et al*., 2001) are provided for comparison. In addition, Table 5 presents foods according to a simple ranking system, which features the top 10 sources of the major carotenoids we analyzed along with an overall score.

Overall, our findings are similar to one or both of the databases we reference. As in their data, our results show variation within each set of food replicates. There are some instances where our data differ markedly from that summarized in the USDA Carotenoid Database or in O'Neill *et al*. (2001). While both raw and cooked carrot contained high levels of α-carotene and β-carotene, it was surprising to find that, per 100 g, celery contained more β-carotene. It is important to remember that in Costa Rica the nutrient-rich leaves at the ends of the stalks are consumed in addition to the stalk itself. Therefore, we included these leaves in the analysis. In addition, the stalk itself is significantly greener than the pale celery typically found in the United States. The Costa Rican celery was also observed to be rich in combined lutein + zeaxanthin. Given the comparably low carotenoid values reported by the USDA, this may also be attributed to the greener stalk and addition of the leaves.

In Table 1, data are presented on α-carotene content. Our values agree with those reported by Holden *et al*. and O'Neill *et al*. for most of the vegetables and fruits analyzed. Notable exceptions include celery, for reasons discussed previously, avocado, and tomato. The avocado samples were slightly higher than in the US and European database mean values for each analyte, but remained within the wide range of individual measurements that were used to tabulate the US and European databases we referenced. The tomato samples we analyzed were rather pale in color and, therefore, were expected to contain levels of carotenoids at the low end of previously reported ranges. These were acceptable samples, however, as pale tomatoes are a common occurrence in everyday life.

Table 2 presents β-carotene content. Several foods showed significantly higher levels than what was reported in the other databases, including avocado, broccoli (cooked), green beans (cooked), cantaloupe, peaches (canned), and tangerine. Once again, celery was found to contain significantly higher levels of β-carotene than expected. Interestingly, raw cilantro, sweet potato, and peas were found to contain lower levels than in the US and/or European databases. This may be due to the particular subspecies examined or differences in cultivation and storage variables.

There was little data available on lycopene in the US and European databases, as seen in Table 3. We found small amounts in avocado, broccoli, lettuce, and peaches (canned) whereas the US database found none. This may be an instrument sensitivity issue, or perhaps the result of insufficient starting material used to detect trace amounts. We detected notably higher levels of lycopene in cantaloupe and papaya that, as mentioned previously, may be due to differences in subspecies cultivation or storage of plants grown in tropical regions. The noticeably pale tomato and watermelon samples yielded lower levels than the referenced databases, as expected based on their appearance. Also lower in lycopene, the ketchup samples were considerably more watery than those found commercially in the US and Europe.

Table 4 presents several differences between our data and the reference databases (Holden *et al*., 1999; O'Neill *et al*., 2001) for β-cryptoxanthin and combined lutein + zeaxanthin. This analysis found significantly more lutein + zeaxanthin in broccoli (cooked), celery, green beans (cooked), iceberg lettuce, orange, peaches (canned), red sweet pepper (cooked and raw), and tangerine. Similarly, we found avocado, cilantro (cooked), peaches (canned), and tangerine to be higher in β-cryptoxanthin. Aside from the celery, which we have already discussed as being due to the inclusion of leaves in the Costa Rican diet, the other foods may exhibit higher levels from increased carotenogenesis due to their tropical growing conditions. Peas

Table 5. Ranking (10 to 1) of the top 10 foods in each nutrient category

	Rank					
English name	*Lutein+zeaxanthin*	*β-Cryptoxanthin*	*Lycopene*	*α-Carotene*	*β-Carotene*	*Overall*
Celery, cooked	10	3	6	7	10	36
Carrot, raw			5	10	9	24
Cilantro, cooked	8	9			6	23
Red sweet pepper, cooked	5	8		4	4	21
Carrot, cooked			2	9	8	19
Broccoli	9		3		5	17
Red sweet pepper, raw	2	5	4	2	2	15
Cilantro, raw	4	10				14
Papaya		4	7			11
Tomato, ketchup			10			10
Mustard greens, cooked	6				3	9
Watermelon			9			9
Marañon		2		5	1	8
Plantain, green cooked				8		8
Tomato, raw			8			8
Melon, cantaloupe					7	7
Spinach, cooked	7					7
Tangerine		7				7
Peaches, canned		6				6
Plantain, ripe cooked				6		6
Lettuce, iceberg	3					3
Squash, ayote cooked				3		3
Avocado		1				1
Banana				1		1
Lettuce, local variety	1					1
Pejibaye			1			1

These data do not reflect per-capita consumption of each food. Ranking of 10 is the highest.

were found to contain less lutein+zeaxanthin than the referenced databases, possibly due to subspecies or cultivation differences. Corn was also lower, but is probably due to the fact that our sample, as is most corn in Costa Rica, was all white. North American and European 'maize' tends to contain some or all yellow kernels, which are visibly higher in carotenoids.

Table 5 provides a summary of the carotenoid value of the foods analyzed. The top 10 sources of each carotenoid are designated 10 through one, with 10 being the top source. The designations are then summed to produce an overall rank of the source value of the food. The higher the rank, the greater the amount and variety of these compounds the food provides. While this ranking system does not take into account per-capita consumption, it does show which foods would be rich sources of carotenoids.

In addition to the fruits and vegetables reported in the tables, we examined several grains, meats, eggs, dairy products, and oils common to the Costa Rican diet. The majority of these products contained carotenoid levels per 100 g that were less than our detection limits and, therefore, were not reported. Notable exceptions include eggs (with combined lutein+zeaxanthin of 2450 μg/100 g), liver (with β-carotene of 8355 μg/100 g), virgin olive oil (with combined lutein+zeaxanthin of 793 μg/100 g and β-carotene of 734 μg/100 g), and most margarines (with varying high levels of β-carotene generally added as a colorant, from 509.16 μg/100 g to 4357.97 μg/100 g).

While methodological variation will impart some degree of fluctuation to the samples within this study, our quality control data suggest that the true cause lies outside of the laboratory—an issue we anticipated from the beginning. Foods were intentionally selected from very different sources to account for variation between a single food grown, stored, and sold under different conditions. Factors such us vine-ripening versus forced chemical ripening, refrigeration, and length of time from harvest to consumption have largely unexpected effects on the ultimate carotenoid concentration. So a red pepper from your own backyard garden may contain somewhat different levels of β-carotene than one purchased at the supermarket. The USDA and European databases report differences as well. But as summaries of existing data from numerous studies, they also face variation due to methodological differences.

With the publication of this database, we hope to provide studies involving Costa Rican and other Latin American populations with accurate carotenoid intake estimates of foods commonly found in tropical diets. The data presented here provide information specifically focused on tropical populations whose eating habits differ markedly than those of North America or Europe. In addition, we hope this data will add to previously published databases and, in doing so, make the pool of carotenoid data available on foods more robust.

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