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Journal of Food Composition and Analysis 19 (2006) 196–204

JOURNAL OF FOOD COMPOSITION AND ANALYSIS

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Original Article

Tocopherol and tocotrienol contents of raw and processed fruits and vegetables in the United States diet

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Received 27 August 2004; received in revised form 5 August 2005; accepted 16 August 2005

Abstract

Tocopherol and tocotrienol contents of raw fruits and vegetables and processed products were determined by saponification and normal phase liquid chromatography. All samples were either locally obtained or collected as part of the US Department of Agriculture's National Food and Nutrient Analysis Program (NFNAP). All fruits, vegetables and processed products were selected from the USDA Key Foods list. The study included 32 raw and processed fruits, 22 raw vegetables, various tomato products, baked beans, cooked potatoes, frozen broccoli and frozen green peas. α-Tocopherol (α-T) was detectable in all products and usually represented the vitamin E form present in highest quantity. γ-Tocopherol (γ-T) was higher than α-T only in cantaloupes, figs, red raspberries, cauliflower, button mushrooms, lettuce, and green peas. α- and γ-Tocotrienols (α- and γ-T3) were measurable in several fruit and vegetables but at levels usually less than 0.1 mg/100 g.

Keywords: Vitamin E; Fruits; Vegetables; HPLC; Analysis

1. Introduction

Vitamin E consists of four tocopherols (α-, β-, γ- and δ-T) and the corresponding tocotrienols (α-, β-, γ- and δ-T3), which contain unsaturated side chains. RRR-α-T is the most biologically active form. Most plant-derived foods, especially fruits and vegetables, contain low to moderate levels of vitamin E activity; but, due to the abundance of plant-derived foods in our diets, they provide a significant and consistent source of vitamin E (Eitenmiller and Lee, 2004).

Since the 1950s, several reports have been published on the vitamin E content of fruits and vegetables (Harris et al., 1950; Booth, 1963; Booth and Bradford, 1963a; McLaughlin and Weihrauch, 1979; Bauernfeind, 1980; Piironen et al., 1986; Eitenmiller and Lee, 2004). The amount of vitamin E in fruits and vegetables is affected by species, variety, maturity, growing conditions (weather, growing season, intensity of sunlight, and soil state), uneven distribution of tocopherols, and time and manner of harvesting (Bauernfeind, 1980). Even after harvest, variation in the vitamin E values is caused by many factors including processing procedures, storage time and conditions, sample preparation and variation in analytical methods (Booth, 1963; Booth and Bradford, 1963b; McLaughlin and Weihrauch, 1979; Kanner et al., 1979; Hamauzu and Chachin, 1995; Rupérez et al., 2001; Eitenmiller and Lee, 2004). In 1979, the first comprehensive compilation of the US Department of Agriculture (USDA) of the tocopherol and tocotrienol composition of foods was published by McLaughlin and Weihrauch (1979). They collected data from the literature published from about 1955 to 1979; unpublished data from industries, universities, and special reports were also included. Eitenmiller and Lee (2004) compiled tocopherol and tocotrienol data on 55 fruit and fruit products and 144 vegetable and vegetable products from literature sources published primarily after 1980 that used liquid chromatographic methods. A comprehensive research study (Piironen et al.,

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0889-1575/$ - see front matter © 2005 Published by Elsevier Inc.
doi:10.1016/j.jfca.2005.08.001

1986) on tocopherols and tocotrienols in Finnish foods (75 commodities of fruits, vegetables, and berries) provided excellent data. However, in many reports, generally only α-T was determined and complete information of the tocopherol and tocotrienol composition of fruits and vegetables is lacking. Availability of liquid chromatographic methods of analysis that can resolve the eight vitamin E forms potentially present in foods has greatly expanded our ability to reliably quantitate vitamin E levels and provide improved compositional information.

Recently, a 5-year research program, the National Food and Nutrient Analysis Program (NFNAP), was designed by the USDA to significantly improve the quality of food composition data (Pehrsson et al., 2003). The NFNAP sampling plan is designed to ensure nationwide representative food samples for nutrient analysis, providing more accurate, representative, and statistically robust estimates for components of important foods in the US food supply (Pehrsson et al., 2000). For sampling, the US was divided into four regions, with nearly equal populations; each region was divided into three strata of nearly equal population. Generalized Consolidated Metropolitan Statistical Areas (GCMSAs) were selected in each stratum proportional to population size and supplemented with contiguous counties when the GCMSAs contained less than 10 grocery stores. Individual brands and varying package sizes were selected using current market volume share data (as pounds consumed). The object of this study was to provide reliable vitamin E data for fruit, vegetables, and their cooked or processed products present in the diet of the United States. This study reports data on 32 raw and processed fruits, 22 raw vegetables, various tomato products, baked beans, cooked potatoes, frozen broccoli and frozen green peas. The data represents assay of 214 fruit samples and 329 vegetable samples collected through USDA sampling protocols.

2. Materials and methods

2.1. Sampling and pretreatment

All samples were either obtained locally as part of earlier USDA sampling programs or collected as a part of the USDA's NFNAP. All fruits, vegetables and processed products were selected from the USDA Key Foods list. The Key Foods approach identifies those foods that contribute significant amounts of nutrients of public health interest to the diet (up to 75% of any one nutrient) (Haytowitz et al., 2002). Individual samples for the foods ranged from 1 to 32. A total of 214 fruit samples and 329 vegetable samples were collected through USDA sampling protocols. The food samples were received at the Food Analysis Laboratory Control Center (FALCC) at Virginia Polytechnic Institute and State University, where they were logged in and processed. The edible portions of samples were cut into small pieces, homogenized in a blender, and stored in the freezer at −60 °C until FALCC sends them to laboratories for analysis. When analyzed, the samples were thawed in the refrigerator at 2–8 °C overnight prior to mixing. After thawing, the samples were removed from the refrigerator and allowed to sit for 20 min at room temperature before analysis. For quality control (QC), soybean oil was purchased from retail stores in Athens, GA. The soybean oil was transferred (10 mL) to amber vials and stored in a freezer (−50 °C). The oil was thawed and allowed to equilibrate to room temperature for 12 h before analysis. Assays were done in duplicate for food and QC samples.

2.2. Standard preparation

Tocopherol standards (α-, β-, γ- and δ-T) were obtained from Sigma (St. Louis, MO). Purity and stability of standards were monitored by E1% 1 cm values (Scott, 1978) measured using a DU-64 Spectrophotometer (Beckman Instruments Inc., Fullerton, CA). Concentrations were calculated from peak areas determined by the Waters 764 integrator (Millipore Corp., Cary, NC) and linear regression.

2.3. Recovery and quality control

The amount of each vitamin E form added to the samples corresponded to 50–150% of expected vitamin E levels in the food samples. These levels were determined for each matrix from existing databank or literature values, if available. Otherwise, similar products with available literature values were used as guides to estimate proper spiking levels. Recovery was calculated by the following equation:

$$R\% = [(Cs - Cp)/Ca]100,$$

where R (%) is the percent recovery of added standard; Cs the tocopherol content in spiked sample; Cp the tocopherol content in sample; and Ca the tocopherol standard added.

The QC sample (soybean oil) was assayed for α-, β-, γ-, and δ-T to check the effect of minor changes in the analytical parameters (e.g., eluent composition, temperature, and column quality) on the separation and the quantitative results. About 0.1 g of soybean oil was weighed into a 25 mL volumetric flask and diluted with mobile phase containing 0.01% butylated hydroxyl toluene (BHT). In order to determine γ- and δ-T in the oil, necessary dilutions (1–25, v/v) were made. The QC oil was assayed at 1 week intervals in duplicate. Additionally, chromatographic QC parameters including the column capacity factor (k), the column selectivity factor (S), and the resolution (R) were determined to evaluate the quality of HPLC system. For this, standard solution was injected in duplicate on the same day. Chromatographic QC parameters were calculated based on equations given by Ye et al. (2001). A representative chromatogram of soybean oil is provided in Fig. 1.

2.4. Saponification and extraction

For the analysis of vitamin E, 20 mL of ethanol containing pyrogallol (6% m/v) was added to each sample (4–5 g) in each extracting tube and agitated to avoid agglomeration. After sonication for 10 min, 5 mL of 60% potassium hydroxide in deionized water (freshly prepared) was added. The extracting tube was flushed with nitrogen gas for 1 min and then connected to an air condenser. The contents were digested for 30 min in a shaker water bath adjusted to 70 °C. The digested samples were cooled in an ice bath after sonication for 10 min. Twenty milliliter of 2% sodium chloride in deionized water was added to each tube. The saponified mixture was extracted two times with 10 mL of extraction solvent (hexane:ethyl acetate, 85:15, v/v) containing 0.05% BHT, and the extraction solvents were combined into a 50 mL volumetric flask. The volume was adjusted to 50 mL with extracting solvent followed by filtration using 0.45 μm nylon membrane filter. A 1.0 mL aliquot of the combined filtrates was evaporated under nitrogen gas and then made to the appropriate concentration of analyte with mobile phase for HPLC assay (Lee et al., 2000).

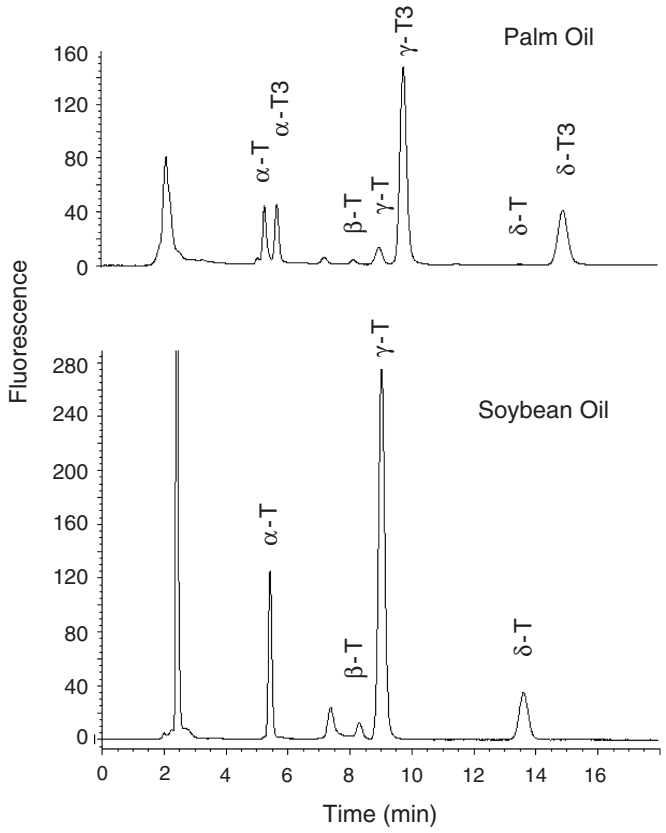

Fig. 1. Chromatograms of palm oil and soybean oil.

2.5. HPLC quantitation

The normal phase HPLC system consisted of a Shimadzu LC-6A pump equipped with a Shimadzu RF-10A spectrofluorometric detector (Shimadzu Corp.), a SpectraSeries AS100 autosampler (Thermo Separation Products Inc., San Jose, CA), and a 25 cm × 4 mm, 5 μm Lichrosorb Si60 column (Hibar Fertigsäule RT. Darmstadt, F.R. Germany). The isocratic mobile phase contained 0.9% isopropanol in *n*-hexane (J.T. Baker chemical Co., Phillipsburg, NJ). The flow rate was 1.0 mL/min. The mobile phase was filtered using a 0.22 μm nylon membrane filter (MSI Inc., Westboro, MA) and de-gassed by stirring under vacuum. The wavelengths were set at 285 nm for excitation and 325 nm for emission for the determination of tocopherols and tocotrienols. Tocopherol peaks were identified by comparison of retention times to the standards. Palm oil which contains relatively large amount of γ-T3 and lower amounts of α-T3 and δ-T3 was chromatographed (Fig. 1) to provide reference retention

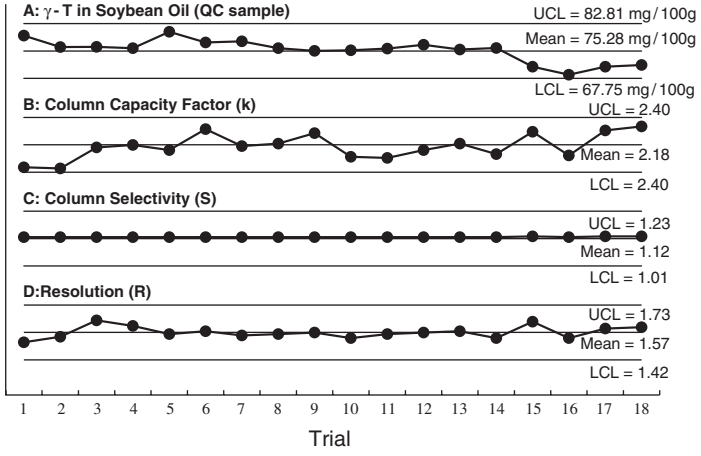

Fig. 2. The quality control charts for γ-T in soybean oil (A) (QC sample) and chromatography parameters (B–D) for γ-T. Column capacity factor (k) = (tR–$t0$)/$t0$; Column selectivity (S) = (tR2–$t0$)/(tR1–$t0$); Resolution (R) = $2\Delta t/(w2–w1)$, where tR = retention time of solute; $t0$ = retention time of unretained components; $tR1$ and $tR2$ = retention times of components 1 and 2, respectively; Δt = difference between retention times of peaks 1 and 2; $w1$ and $w2$ = width of peak 1 and 2 at baseline, respectively. UCL = upper control line; LCL = lower control line, Charts repeat 18 runs.

times for identification of the tocotrienols in the fruits and vegetables. When tocotrienols are present in fruits and vegetables, they are usually present as α-T3 and γ-T3 at much lower concentrations than the tocopherols. β-T3 and δ-T3 were not found in any of the fruits and vegetables included in this study. We prefer to use palm oil instead of high cost tocotrienol standards to determine tocotrienol retention times. The relatively high levels of α-T3 and δ-T3 in the oil provide excellent cross reference to retention times for α-T3 and δ-T3 in fruits and vegetables.

The tocopherol concentrations in the samples were calculated in mg/100 g of edible weight using the average peak area compared between standard and sample after duplicate injections. Peak responses for tocopherols were used to quantify the corresponding tocotrienols (Thompson and Hatina, 1979). All tocopherol and tocotrienol values were corrected for recovery.

3. Results and discussion

3.1. Evaluation of separation conditions

Fig. 2 provides the QC charts for analytical and chromatographic parameters including column capacity factor (k), column selectivity (S) and resolution (R) for γ-T. Data for α- and δ-T are not presented. Each data point in (A) indicates the content of γ-T in the QC sample (soybean oil) assayed at approximately 1 week intervals. All data were close to the mean lying between the upper control line (UCL) and lower control line (LCL) which are set by ±10% of the mean. Each point in (B) indicates the calculated k values for γ-T in the standard. S and R values were calculated between the adjacent peaks, β- and γ-T, in the standard solution. The capacity factor is a measure of a compound's (γ-T) retention in terms of the column

Table 1
Analytical recovery values for fruit, vegetables, and various products

Sample		Recovery (%)			
		α-Tocopherol	β-Tocopherol	γ-Tocopherol	δ-Tocopherol
Fruit					
1	Apples ($n = 2$)	100	92.2	97.6	93.2
2	Apple sauce ($n = 2$)	93.4	98.7	94.3	94.1
3	Avocadoes ($n = 4$)	95.1±10.29	82.3	93.6±9.24	99.2±8.86
4	Bananas ($n = 1$)	92.5	ND[a]	94.8	91.1
5	Cherries ($n = 2$)	92.9	100	94.2	106.7
6	Fruit cocktail ($n = 2$)	101.6	93.8	92.7	91.8
7	Figs ($n = 2$)	81.8	ND	81.2	ND
8	Grapefruit ($n = 2$)	94.0	96.8	98.4	84.2
9	Kiwi ($n = 1$)	95.4	ND	96	ND
10	Nectarines ($n = 3$)	96.1±6.70	100.0	96.3±9.18	95.0
11	Olives ($n = 2$)	117.1	100.5	91.6	97
12	Oranges ($n = 2$)	95.6	98.9	100.7	93.3
13	Orange juice ($n = 2$)	91.9	100.0	91.5	100.5
14	Peaches ($n = 2$)	107.1	97.8	98.0	96.5
15	Plums ($n = 1$)	89.7	ND	87.6	110.2
16	Prune juice ($n = 2$)	101.0	100.0	88.4	89.7
17	Raspberries ($n = 2$)	98.4	ND	96.2	ND
18	Strawberries ($n = 3$)	89.4±1.96	ND	89.2±5.36	ND
19	Watermelon ($n = 2$)	106.2	97.8	96.7	94.8
Mean±S.D. (19 fruit)		96.8±7.72	96.8±5.04	93.6±4.63	95.8±6.49
Vegetables					
1	Asparagus ($n = 4$)	92.6±3.29	97.3±8.43	94.9±4.50	100.2±1.01
2	Broccoli ($n = 3$)	101.1±6.58	92.0±0.14	94.3±2.44	101.4±4.09
3	Brussels sprout ($n = 2$)	98.9	100.8	97.9	101.8
4	Carrots ($n = 7$)	92.3±6.95	98.7±7.14	91.6±10.88	97.9±3.32
5	Celery ($n = 2$)	93.6	94.3	93.5	98.0
6	Corn ($n = 2$)	101.6	95.6	96.5	95.1
7	Lettuce ($n = 5$)	97.8±6.56	102.3	101.4±9.17	101.4±5.39
8	Okra ($n = 2$)	105.0	98.1	88.9	91.1
9	Onions ($n = 2$)	92.6	90.0	99.4	108.3
10	Parsley ($n = 2$)	96.4	92.1	90.5	92.3
11	Peppers ($n = 2$)	99.6	100.0	90.6	87.5
12	Spinach ($n = 5$)	98.6±9.91	100.0	95.6±3.85	92.4±5.66
13	Tomatoes ($n = 2$)	104.7	ND	100.7	108.3
14	Tomato products ($n = 4$)	104.7±6.46	ND	94.2±7.57	93.9±8.80
Mean±S.D. (14 vegetables)	98.2±4.66	96.8±3.95	94.8±4.66	97.8±6.21	

[a]ND = not determined.

Table 2
Tocopherol and tocotrienol contents of fruit (mg/100 g edible weight)[a]

Fruit	No.	α-T[b]	β-T	γ-T	δ-T	α-T3[c]	γ-T3	Total
Apples								
Golden delicious	2	0.09	0.01	—	—	—	—	0.10
Red delicious	2	0.38	—	0.04	0.01	—	—	0.43
Unspecified	10	0.21±0.11	—	—	—	—	—	0.21±0.11
Applesauce	2	0.21	—	—	—	—	—	0.21
Avocadoes								
Florida	2	2.66	0.08	0.39	—	—	—	3.13
Fuerte	2	1.33	0.03	0.13	—	0.03	—	1.52
Haas	2	1.93	0.06	0.69	0.03	0.04	—	2.75
Unspecified	8	1.81±0.36	0.03±0.01	0.13±0.02	0.02±0.00	—	—	1.98±0.38
Bananas	16	0.13±0.10	—	Tr	—	0.02±0.03	—	0.15±0.09
Blackberries	3	1.43±0.74	0.04±0.02	1.42±0.15	0.85±0.33	—	—	3.74±0.94
Blueberries	4	0.58±0.21	Tr	0.38±0.09	0.02±0.03	—	0.08±0.01	1.05±0.31
Cantaloupes	12	0.06±0.02	—	0.10±0.02	—	—	—	0.16±0.03
Cherries								
Fresh, unspecified	4	0.06±0.03	—	—	—	Tr	—	0.08±0.03
Bing	2	0.08	0.02	0.07	—	0.07	—	0.24
Canned	2	0.23	—	—	—	—	—	0.23
Clementine	3	0.20±0.06	—	—	—	—	—	0.20±0.06
Coconut	2	—	—	0.07	—	0.79	0.18	1.04
Cranberries	4	1.23±0.20	Tr	0.04±0.00	—	—	0.33±0.08	1.61±0.27
Dates	4	0.06±0.03	Tr	0.06±0.03	—	Tr	—	0.13±0.05
Figs	4	0.34±0.08	Tr	0.38±0.28	Tr	0.03±0.03	—	0.76±0.35
Fruit cocktail								
Heavy syrup	2	0.40	—	—	—	—	—	0.40
Lite syrup	2	0.50	—	—	—	—	—	0.50
Grapefruit	10	0.16±0.06	—	—	—	Tr	—	0.17±0.07
Grape, white seedless	6	0.38±0.22	—	0.16±0.16	—	—	—	0.54±0.18
Honeydew melon	4	0.03±0.01	—	0.03±0.00	—	—	—	0.06±0.01
Kiwi	4	1.31±0.03	—	0.03±0.01	—	—	0.11±0.02	1.45±0.05
Nectarines	6	0.70±0.26	Tr	0.02±0.02	0.01±0.02	—	—	0.73±0.24
Olives								
Green, bottled	2	3.81	—	—	—	—	—	3.81
Ripe, canned	2	1.65	—	—	—	—	—	1.65
Oranges	2	0.25	—	—	—	—	—	0.25
Orange juice								
Fresh	2	0.06	—	—	—	—	—	0.06
Frozen, concentrate	2	0.17	—	—	—	—	—	0.17
Peaches								
Fresh	6	0.71±0.23	—	0.02±0.02	—	0.02±0.04	—	0.76±0.24
Canned, lite syrup	2	0.79	—	—	—	—	—	0.79
Dried	2	0.19	—	—	—	—	—	0.19
Frozen	2	0.63	—	—	—	—	—	0.63
Unspecified	2	1.19	—	0.04	—	—	—	1.23
Pears								
Fresh	6	0.21±0.14	0.01±0.01	0.08±0.07	—	0.12±0.15	—	0.42±0.36
Dried	2	0.06	—	0.04	—	—	—	0.10
Pineapple	7	0.02±0.00	—	—	—	0.02±0.01	—	0.04±0.02
Plums	6	0.28±0.11	—	0.05±0.08	—	0.02±0.04	0.22±0.19	0.79±0.39
Prunes	2	0.37±0.13	0.01±0.03	0.03±0.01	Tr	Tr	—	0.41±0.13
Prune juice, canned	10	0.12	—	—	—	—	—	0.12
Raspberries, red	6	0.85±0.19	0.09±0.03	1.39±0.33	1.15±0.41	—	—	3.46±0.36
Raisins	10	0.11±0.04	—	0.04±0.01	—	0.01±0.01	—	0.16±0.05
Strawberries	8	0.28±0.07	Tr	0.08±0.03	0.04±0.01	0.01±0.01	—	0.41±0.07
Watermelon	9	0.05±0.02	—	—	Tr	Tr	—	0.06±0.02

[a]Mean±S.D.; Tr = trace amount; — = not detectable; LOD (Limit of detection, ng/20 μl) = 0.23 (α-T) and 0.12 (γ-T); LOQ (Limit of quantitation, ng/20 μl) = 0.32 (α-T) and 0.17 (γ-T).
[b]T = tocopherol.
[c]T3 = tocotrienol.

Table 3
Tocopherol and tocotrienol contents of vegetables and processed vegetable products (mg/100 g edible weight)[a]

Samples	No.	α-T[b]	β-T	γ-T	δ-T	α-T3[c]	γ-T3	Total
Asparagus								
Frozen, blanched	2	1.07	0.02	0.13	—	0.02	—	1.24
Frozen, boiled	2	1.07	—	0.13	—	—	—	1.20
Green, frozen	2	0.04	—	0.08	0.01	—	—	0.13
Unspecified	8	1.14±0.77	0.03±0.01	0.14±0.07	—	—	—	1.31±0.84
Broccoli								
Raw	8	1.44±0.22	Tr	0.31±0.12	—	Tr	—	1.77±0.34
Boiled	4	2.02±0.51	Tr	0.36±0.17	—	—	—	2.43±0.33
Steamed	4	1.45±0.16	Tr	0.30±0.10	—	—	—	1.76±0.16
Frozen, blanched	8	1.08±0.18	—	0.24±0.11	—	—	—	1.32±0.26
Frozen, boiled	2	1.13	—	0.26	—	—	—	1.39
Brussels sprout								
Boiled	2	0.43	—	—	—	—	—	0.43
Frozen, blanched	2	0.38	—	—	—	—	—	0.38
Cabbage								
Red	2	0.07	—	—	—	0.05	—	0.12
White	2	0.21	—	—	—	0.04	—	0.25
Unspecified	4	0.05±0.03	—	—	—	0.33±0.04	0.32±0.05	0.69±0.07
Carrots								
Raw	10	0.86±0.44	0.01±0.01	—	—	—	—	0.87±0.45
Frozen, blanched	6	0.70±0.05	0.01±0.01	—	—	—	—	0.71±0.04
Frozen, boiled	6	0.81±0.01	0.01±0.01	—	—	—	—	0.83±0.01
Frozen, microwaved	6	0.69±0.10	0.01±0.01	—	—	—	—	0.71±0.12
Cauliflower	2	0.08	—	0.20	—	0.06	—	0.34
Celery	14	0.26±0.25	—	—	—	Tr	—	0.27±0.24
Corn								
Cream, canned	2	0.07	0.01	0.10	—	—	0.21	0.38
Frozen, boiled	2	0.07	—	0.14	—	0.21	0.66	1.08
Frozen, blanched	2	0.06	—	0.51	—	0.38	1.02	1.97
Kernel, canned	2	0.03	—	—	—	0.12	1.30	1.45
Cucumber	2	0.03	0.01	0.04	—	0.08	—	0.16
Lettuce								
Iceburg	12	0.22±0.10	—	0.11±0.09	—	—	—	0.33±0.15
Butterhead	4	0.23±0.12	—	0.27±0.09	—	—	—	0.50±0.17
Leaf	2	0.31	0.01	0.74	—	—	—	1.06
Romaine	2	0.55	—	0.36	—	—	—	0.91
Unspecified	32	0.18±0.13	—	0.31±0.14	0.01±0.01	0.01±0.02	—	0.50±0.22
Mushrooms, button	2	0.01	0.01	0.02	0.02	0.07	—	0.13
Mustard spread	2	0.30	—	1.93	—	—	—	2.23
Okra	2	0.27	—	0.16	—	—	—	0.43
Onions								
White	2	0.04	—	—	—	0.12	—	0.16
Boiled	2	0.01	—	—	—	0.12	—	0.01
Unspecified	4	0.02±0.01	—	0.01±0.01	—	0.02±0.02	—	0.04±0.03
Parsley	2	0.75	—	0.53	—	—	—	1.28
Pea, Green								
Frozen, blanched	6	0.02±0.01	—	0.75±0.13	0.01±0.01	—	—	0.78±0.14
Canned	2	0.02	—	1.70	0.03	—	0.05	1.80
Peppers								
Chili	2	0.16	—	—	—	—	—	0.16
Green, sweet	2	0.08	—	—	—	—	—	0.08
Potatoes								
Raw	25	0.07±0.03	—	—	—	0.01±0.01	—	0.06±0.04
Boiled	13	0.06±0.02	—	—	—	0.01±0.01	—	0.06±0.03
Radishes	4	Tr	—	—	—	0.02±0.01	—	0.02±0.01
Spinach								
Raw	8	1.96±0.43	—	0.21±0.06	—	—	—	2.11±0.52
Frozen, blanched	5	2.64±0.33	—	0.14±0.01	—	—	—	2.78±0.34
Frozen, boiled	3	3.56±0.21	0.01±0.01	0.17±0.01	—	—	—	3.74±0.22
Frozen, microwaved	3	4.00±0.39	0.01±0.01	0.19±0.03	0.01±0.02	—	—	4.22±0.44
Sweet potatoes								
Raw	2	0.25	0.01	—	—	0.10	—	0.36
Baked	2	0.16	—	—	—	0.04	—	0.20

Table 3 (*continued*)

Samples	No.	α-T[b]	β-T	γ-T	δ-T	α-T3[c]	γ-T3	Total
Tomatoes								
Raw, unpeeled	20	0.53±0.22	Tr	0.14±0.06	Tr	Tr	—	0.68±0.22
Raw, peeled	2	0.59	—	0.07	—	—	—	0.66
Boiled	12	0.52±0.13	Tr	0.22±0.04	Tr	Tr	—	0.76±0.15
Tomato products								
Whole tomato, canned	9	0.79±0.16	0.01±0.01	0.05±0.01	—	—	—	0.86±0.17
Juice, canned	6	0.77±0.07	0.02±0.01	0.04±0.02	—	—	—	0.83±0.05
Ketchup	4	1.33±0.05	0.02±0.01	0.09±0.02	0.01±0.01	—	—	1.45±0.07
Sauce, canned	9	1.36±0.15	0.03±0.01	0.07±0.02	—	—	—	1.46±0.16
Paste, canned	3	4.66±0.20	0.05±0.00	0.24±0.04	—	—	—	4.98±0.24
Puree, canned	2	1.95	0.02	0.10	—	—	—	2.08
Pasta sauce, no meat	6	2.28±0.24	0.03±0.00	0.97±0.33	0.09±0.10	—	—	3.42±0.36
Salsa sauce, bottled	2	1.26	0.01	0.10	—	—	—	1.38
Vegetables								
Juice, mixed	2	0.70	—	—	—	—	—	0.70
Baby food, mixed	1	2.72	0.02	0.50	0.13	—	0.25	3.62

[a]Mean±S.D.; Tr = trace amount; — = not detectable; LOD (Limit of detection, ng/20 μl) = 0.23 (α-T) and 0.12 (γ-T); LOQ (Limit of quantitation, ng/20 μl) = 0.32 (α-T) and 0.17 (γ-T).
[b]T = tocopherol.
[c]T3 = tocotrienol.

volumes. A k value of 2–6 is preferable (Pomeranz and Meloan, 1994). Column selectivity, also referred to as the separation factor, is the ratio of net times $((tR2-t0)/(tR1-t0))$ for any two components in a column. A column selectivity value above 1.0 indicates peak resolution. A larger R value means better separation; baseline separation requires R values equal to or greater than 1.5. The values of S (1.12) and R (1.57) show good separation between the β- and γ-T peaks, which is an advantage of normal phase compared to reversed-phase HPLC.

3.2. Recovery

Recoveries for tocopherols varied depending on sample matrix, but recovery values for most of the fruit and vegetables were over 90% (Table 1). The % mean recoveries ±S.D. in 19 fruit ($n = 39$) were 96.8±7.7, 96.8±5.0, 93.6±4.6, and 95.8±6.5 for α-, β-, γ-, and δ-T, respectively. The % mean recoveries ±S.D. of 14 vegetables ($n = 44$) were 98.2±4.7 for α-, 96.8±4.0 for β-, 94.8±4.7 for γ-, and 97.8±6.2 for δ-T. These recoveries were used to correct the contents of tocopherols and tocotrienols in samples assayed in this study.

3.3. Determination of tocopherols and tocotrienols

The tocopherol and tocotrienol compositions of the fresh fruits and vegetables, various tomato products, and their cooked or processed products are shown in Tables 2 and 3. β- and δ-T3 were not detected in any of the samples. α-T was detectable in all products except coconut and usually represented the vitamin E form present in highest quantity. In fruits, green olive showed the highest α-T content (3.81, mg/100 g), followed by avocado (Florida, 2.66; Haas, 1.93; unspecified. 1.81), blackberries (1.43), kiwi (1.31), and cranberries (1.23). Among vegetables and their products, α-T levels (mg/100 g) were relatively high in tomato products (0.52–4.66), spinach (1.96–4.00), and broccoli (1.08–2.02). γ-T was higher than α-T in some products including cantaloupes, coconut, figs, red raspberries, cauliflower, corn products, cucumber, lettuce (Butterhead, Leaf), mushrooms, mustard spread, and green peas. α- and γ-T3 were measurable in some fruits and vegetables but at levels usually less than 0.1 mg/100 g. α-T3 was the predominant vitamin E form in coconut (0.79). The γ-T3 levels (mg/100 g) were relatively high in cranberries (0.33), cabbage (0.32), kiwi (0.11), plums (0.22), and corn products (not detectable to 1.30). The α-T levels of fruits and vegetables (mg/100 g) varied depending on species: apples (0.09–0.38), avocadoes (1.33–2.66), and lettuce (0.18–0.55). Red delicious, Florida, and Romaine cultivars contained higher α-T content than the other apple, avocado, and lettuce cultivars assayed in this study, respectively. Data in Table 3 shows that heat-processing procedures including blanching and boiling had little effect on the vitamin E content of vegetables. In some cases, blanching or boiling can increase vitamin E content through large losses of water-soluble components. In our data, higher vitamin E levels are present in boiled broccoli and blanched and boiled spinach, compared to raw products. In other vegetables, little change was noted in vitamin E content between raw and heat processed vegetables. Table 4 ranked fruits and vegetables by α-T content (mg/100 g edible weight). Tomatoes, condensed tomato products, spinach, avocadoes and broccoli showed high ranking in α-T content. The recent Institute of Medicine report on vitamin E (IOM (Institute of Medicine), 2000) has a Recommended Dietary Allowance (RDA) of 15 mg/day of α-T. This RDA is based only on the α-T form of vitamin E.

Table 4
Ranking of fruit and vegetables by α-tocopherol content

Fruit or vegetable	α-T mg/100 g edible wt[a]	Fruit or vegetable	α-T mg/100 g edible wt[a]
Tomato paste	4.7	Lettuce, leaf	0.3
Spinach, blanched, frozen, microwaved	4.0	Mustard spread	0.3
Olives, green, bottled	3.8	Plums	0.3
Spinach, blanched, frozen, boiled	3.6	Strawberries	0.3
Tomato product, baby food	2.7	Okra	0.3
Avocadoes, Florida	2.7	Celery	0.3
Spinach, blanched, frozen	2.6	Sweet potatoes, raw	0.3
Tomato pasta sauce, no meat	2.3	Cherries, canned	0.2
Broccoli, boiled	2.0	Lettuce, Butterhead	0.2
Spinach, raw	2.0	Lettuce, Iceburg	0.2
Tomato puree	2.0	Apples, unspecified	0.2
Avocadoes, Haas	1.9	Applesauce	0.2
Avocadoes, unspecified	1.8	Pears, fresh	0.2
Olives, ripe, canned	1.7	Cabbage, white	0.2
Broccoli, steamed	1.5	Peaches, dried	0.2
Broccoli, raw	1.4	Lettuce, unspecified	0.2
Blackberries	1.4	Orange juice, concentrate, frozen	0.2
Tomato sauce, canned	1.4	Grapefruit	0.2
Avocadoes, Fuerte	1.3	Peppers, chili	0.2
Tomato ketchup	1.3	Sweet potatoes, baked	0.2
Kiwi	1.3	Clementine	0.2
Tomato salsa sauce, bottled	1.3	Bananas	0.1
Cranberries	1.2	Prune juice	0.1
Peaches, unspecified	1.2	Raisins	0.1
Broccoli, blanched, frozen, boiled	1.1	Apples, Golden Delicious	0.1
Broccoli, blanched, frozen	1.1	Cherries, Bing	0.1
Asparagus, blanched, frozen	1.1	Cauliflower	0.1
Asparagus, blanched, frozen, boiled	1.1	Peppers, green, sweet	0.1
Asparagus, unspecified	1.1	Cabbage, unspecified	0.1
Carrots, raw	0.9	Cabbage, red	0.1
Raspberries	0.9	Corn, cream, canned	0.1
Carrots, blanched, frozen, boiled	0.8	Corn, blanched, frozen, boiled	0.1
Peaches, canned, lite syrup	0.8	Potatoes, raw	0.1
Whole tomato, canned	0.8	Cantaloupes	0.1
Tomato juice, canned	0.8	Cherries, raw, unspecified	0.1
Parsley	0.8	Dates	0.1
Peaches, fresh	0.7	Orange juice	0.1
Nectarines	0.7	Pears, dried	0.1
Carrots, blanched, frozen	0.7	Corn, blanched, frozen	0.1
Vegetable juice	0.7	Potatoes, cooked	0.1
Carrots, blanched, frozen, microwaved	0.7	Watermelon	0.1
Peaches, frozen	0.6	Cabbage	
Tomatoes, raw, peeled	0.6	Asparagus, green, blanched, frozen	0.04
Blueberries	0.6	Onions, white	0.04
Lettuce, romaine	0.6	Honeydew melon	0.03
Tomatoes, raw, unpeeled	0.5	Corn, kernel, canned	0.03
Tomatoes, boiled	0.5	Cucumber	0.03
Fruit cocktail, lite syrup	0.5	Pineapple	0.02
Brussels sprout, boiled	0.4	Onions, unspecified	0.02
Fruit cocktail, heavy syrup	0.4	Green pea, blanched, frozen	0.02
Apples, red delicious	0.4	Green pea, blanched, canned	0.02
Grape, white seedless	0.4	Mushrooms, button	0.01
Brussels sprout, blanched, frozen	0.4	Onions, boiled	0.01
Prunes	0.4	Radishes	Tr
Figs	0.3	Coconut	—

[a]Values rounded to nearest tenth.

4. Conclusions

This study provides vitamin E values for fruit, vegetables and several processed products representing key foods in the diet of the United States. α-T was the vitamin E component found in highest quantity in most fruit and vegetables. α- and γ-T3 were detectable in several fruit and vegetables, but at levels usually less than 0.1 mg/100 g.

Fruit, vegetables and their processed products provide good sources of vitamin E to the US consumer because of the quantity consumed. Especially, tomatoes, condensed tomato products, spinach, and broccoli are significant sources of α-T to the US consumer.

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