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Lipophilic and Hydrophilic Antioxidant Capacities of Common Foods in the United States

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Both lipophilic and hydrophilic antioxidant capacities were determined using the oxygen radical absorbance capacity ($ORAC_{FL}$) assay with fluorescein as the fluorescent probe and 2,2′-azobis(2-amidinopropane) dihydrochloride as a peroxyl radical generator on over 100 different kinds of foods, including fruits, vegetables, nuts, dried fruits, spices, cereals, infant, and other foods. Most of the foods were collected from four different regions and during two different seasons in U.S. markets. Total phenolics of each sample were also measured using the Folin–Ciocalteu reagent. Hydrophilic $ORAC_{FL}$ values (H-$ORAC_{FL}$) ranged from 0.87 to 2641 μmol of Trolox equivalents (TE)/g among all of the foods, whereas lipophilic $ORAC_{FL}$ values (L-$ORAC_{FL}$) ranged from 0.07 to 1611 μmol of TE/g. Generally, L-$ORAC_{FL}$ values were <10% of the H-$ORAC_{FL}$ values except for a very few samples. Total antioxidant capacity was calculated by combining L-$ORAC_{FL}$ and H-$ORAC_{FL}$. Differences of $ORAC_{FL}$ values in fruits and vegetables from different seasons and regions were relatively large for some foods but could not be analyzed in detail because of the sampling scheme. Two different processing methods, cooking and peeling, were used on selected foods to evaluate the impact of processing on $ORAC_{FL}$. The data demonstrated that processing can have significant effects on $ORAC_{FL}$. Considering all of the foods analyzed, the relationship between TP and H-$ORAC_{FL}$ showed a very weak correlation. Total hydrophilic and lipophilic antioxidant capacity intakes were calculated to be 5558 and 166 μmol of TE/day, respectively, on the basis of data from the USDA Continuing Survey of Food Intakes by Individuals (1994–1996).

KEYWORDS: Antioxidants; hydrophilic; lipophilic; $ORAC_{FL}$; total phenolics; fruits; vegetables; nuts; dried fruits; spices; baby foods; chocolate; cereal

INTRODUCTION

Oxidative stress has been associated with the development of many chronic and degenerative diseases, including cancer (*1*), heart disease (*2*), and neuronal degeneration such as Alzheimer's (*3*) and Parkinson's diseases (*4*), as well as being involved in the process of aging (*5*). Reactive oxygen species (ROS) can damage biological molecules such as proteins, lipids, and DNA. ROS are generated as byproducts of normal cell aerobic respiration that is essential to life. The human body has developed a very delicate system, although not 100% effective, to eliminate free radicals from the body (*6*, *7*). Exposure to free radicals from external sources such as cigarette smoke, pollutants, chemicals, and environmental toxins may also occur. Diets rich in fruits and vegetables have been considered as excellent sources of antioxidants (*8*–*10*). Vitamins C and E, polyphenols, and carotenoids have been thought to be responsible for most of the antioxidant activity in foods (*11*, *12*). However, clinical trials using supplements of vitamin C, vitamin E, or carotenoids have provided inconsistent results (*13*–*16*). In terms of disease prevention, clinical trials with whole fruits and vegetables are more likely to give positive results (*17*–*19*), but few carefully controlled studies have been conducted. Until recently, there have not been any databases available to evaluate total antioxidant intake from nutrient as well as "nonnutrient" antioxidants and relate it to health outcomes. The potential importance of such a technique has been demonstrated recently in evaluating relationships between dietary antioxidants and oxidative stress induced diseases; it was observed in data from a population-based case-control study that there was an inverse correlation between total antioxidant capacity intake and the risk of gastric cancer of both the cardia and distal portions of the stomach

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(*20*). These relationships were observed despite a very incomplete database of total antioxidant capacity (only 12 items among the various fruits and vegetables).

The oxygen radical absorbance capacity (ORAC) assay, originally developed by Cao and co-workers (*21*, *22*) based upon the work by Glazer's laboratory (*23*), was selected for this work because of its advantages related to biological systems (*24*, *25*). Ou and co-workers (*26*) introduced fluorescein as the fluorescent probe in the ORAC assay, which made it a more robust method ($ORAC_{FL}$). Recently, Huang and co-workers (*27*) developed an assay for lipophilic components using randomly methylated β-cyclodextrin as a solubility enhancer, which allows for the measurement of the antioxidant capacity of both lipophilic and hydrophilic components in a given sample separately using the same peroxyl-free radical source. It is clear from our work that in order to obtain an accurate total $ORAC_{FL}$ value of a given sample, both lipophilic and hydrophilic fractions need to be measured (*28*).

In this study using $ORAC_{FL}$, we measured for the first time total antioxidant capacity (TAC) combining both lipophilic and hydrophilic antioxidant components in over 100 different foods including fruits, vegetables, nuts, dried fruits, spices, cereals, and other types of foods. At the same time, we measured the total phenolic content of these foods to evaluate their contribution to total antioxidant activity. Phenolic compounds are believed to account for a major portion of the antioxidant capacity in many plants (*29*). Most of the food samples in this study were sampled directly from the U.S. market using statistically validated methods. The intent of the study was not to evaluate many of the factors that affect antioxidant capacity of foods (i.e., genetics, processing, environmental factors such as drought, pests, diseases, etc.), but to provide data on foods that are being consumed by the U.S. population. The results from this study provide a comprehensive set of data that was collected as part of the USDA National Food and Nutrient Analysis Program (NFNAP). These studies will be used to establish an antioxidant capacity database to be posted on the USDA Nutrient's Data Laboratory website (http: www.nal.usda.gov/fnic/foodcomp).

MATERIALS AND METHODS

Chemicals and Apparatus. 2,2′-Azobis(2-amidinopropane) dihydrochloride (AAPH) was purchased from Wako Chemicals USA (Richmond, VA). 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox) and fluorescein (sodium salt) (Fl) were obtained from Aldrich (Milwaukee, WI). Randomly methylated β-cyclodextrin (Trappsol) (Pharm Grade) (RMCD) was obtained from Cyclodextrin Technologies Development Inc. (High Springs, FL). Folin−Ciocalteu's phenol reagent, sodium carbonate, and gallic acid were all purchased from Sigma (St. Louis, MO). Other solvents were purchased from Fisher (Fair Lawn, NJ). Extractions of samples were performed on an ASE 200 accelerated solvent extractor (Dionex Corp., Sunnyvale, CA). ORAC analyses were carried out on a FLUOstar Galaxy plate reader (BMG Labtechnologies, Durham, NC). A fluorescence filter with an excitation wavelength of 485 nm and an emission wavelength of 520 nm was used. Microplates (48 well, Falcon 3230) were purchased from VWR (St. Louis, MO). Total phenolics (TP) were analyzed on an Analette model 9006 chemistry analyzer (Precision Systems Inc., Natick, MA).

Food Sampling Methods. Produce (fruits, nuts, and vegetables) were sampled from retail outlets in 12 cities around the United States in two different seasons (*30*, *31*). Approximately 3 lb of each item was randomly selected from bins in each retail outlet. These samples were composited to form four regional composites: west (Los Angeles, CA; Vancouver, WA; and Longview, WA); central (Wheaton, IL; Conroe, TX; and Beaumont, TX); south (Mena, AR; Springfield, MO; and Franklin, TN); and northeast (Springfield, NJ; Canonsburg, PA; and Franklin, PA). Sweet cherries, green and red grapes, red and green peppers, asparagus, carrots, cucumbers, and cabbage were collected in only one season from the same locations and composited in the same manner. There were normally eight samples for each food item. Other name-brand food items were sampled in 12 cities in the United States and composited to form national composites of one or more brands. Blue corn meal and a beverage prepared from chilchen berries were supplied by Dr. P. Pehrsson, Nutrient Data Laboratory, from samples collected on the Navajo reservation. Agave samples were supplied by the University of New Mexico. The samples were collected and processed in the Food and Analysis Laboratory Control Center, Department of Biochemistry, Virginia Polytechnic Institute and State University (Blacksburg, VA). Fresh composited fruits and vegetables were freeze-dried and kept at −70 °C before analysis. Nuts, dried fruits, spices, and other foods were kept at −70 °C in their original form until analysis.

Cereals, breads, snacks, popcorn, baby foods, apple sauce, tomato sauce, ketchup, salsa, tomato juice, grapefruit juice, lemon juice, and several other fruits and vegetables (apricot, mango, eggplant, spinach, beets, red onion, green bean, cauliflower, pumpkin, green pea, corn, lima bean, orange pepper, yellow pepper, small red beans, black-eye peas, black beans, and navy beans) were purchased from a local supermarket. Solid foods including fresh, frozen, and canned forms were measured in the freeze-dried forms, and the $ORAC_{FL}$ values were converted and expressed on a fresh weight basis. Rice bran was provided by Dr. N. Fang, Arkansas Children's Nutrition, Little Rock, AR.

Two apple varieties (Red Delicious and Golden Delicious) and cucumbers were prepared both with and without peels in order to compare the effect of removing the peel. Ten vegetables (potato, broccoli, broccoli raab, carrot, tomato, asparagus, pepper, onion, sweet potato, and red cabbage) were analyzed in both the raw and cooked forms. Potatoes were baked, whereas the other vegetables were boiled. The protocol for boiling samples was to fill a stainless steel sauce pan about half full with deionized water. Once the water came to a boil, the food samples to be cooked were placed in the pan, filling it approximately two-thirds full, and foods were cooked for 3−4 min. The three potato samples (russet, white, and red) were punctured (six holes per potato) by a nut pick. The russet, white,and red potatoes were baked for 50, 35, and 25 min at 218 °C, respectively.

Sample Preparation. For solid samples (in freeze-dried or original dried forms), extraction was performed on an ASE 200 accelerated solvent extractor. The procedures of sample preparation were based on our previous study (*28*). Briefly, 1 g of each sample was mixed with 5 g of sea sand (Unimin Corp., Le Sueur, MN). Sample and sand were transferred to a 22 mL extraction cell and were initially extracted with hexane/dichloromethane (1:1, Hex/Dc) followed by acetone/water/acetic acid (70:29.5:0.5; AWA).

Extracts from Hex/Dc were dried under nitrogen flow in a 30 °C water bath, and the residue was reconstituted with 10 mL of acetone. After centrifugation, the supernatant was used to measure lipophilic $ORAC_{FL}$ following further dilution with assay buffer as necessary (*28*).

AWA extracts were transferred to a 25 mL volumetric flask and diluted with AWA to 25 mL total volume. This solution was used to measure the hydrophilic $ORAC_{FL}$ and TP after proper dilution.

Liquid (1 mL) or semiliquid samples (1 g) were extracted with 10 mL of AWA in a 15 mL screw-cap tube. After the addition of solvent, the tube was vortexed for 30 s followed by sonication at 37 °C for 5 min. The tube was shaken twice in the middle of sonication to suspend the samples. The tube was kept at room temperature for 10 min. The tubes were vortexed for 30 s after 5 min. Ten minutes later, the tube was centrifuged at 4000 rpm for 10 min and the supernatant was removed. The samples were extracted one more time with 10 mL of AWA using the same procedure, and the supernatants were combined. The combined supernatant was transferred to a 25 mL volumetric flask, and AWA was added to make the final volume 25 mL. The solution from the extracted sample was then diluted as appropriate for the $ORAC_{FL}$ and TP analyses.

Each sample was extracted in duplicate and assayed in duplicate.

ORAC Assay on Plate Reader. Both hydrophilic and lipophilic $ORAC_{FL}$ assays were carried out on a FLUOstar Galaxy plate reader, which was equipped with an incubator and two injection pumps. The temperature of the incubator was set to 37 °C. Procedures were based on our modified ORAC$_{FL}$ method (*32*) and the previous report by Huang and co-workers (*27*). Briefly, AAPH was used as peroxyl generator and Trolox as a standard. Forty microliters of sample, blank, and Trolox calibration solutions were transferred to 48-well microplates in duplicate on the basis of a set layout. To avoid possible positional errors, a "forward-then-reverse" order was always used. The plate reader was programmed to record the fluorescence of FL each cycle.

Parameters of assay for the plate reader were as follows: cycle number, 35; cycle time, 210 s; shaking mode, 8 s orbital shaking (4 mm shake width) before each cycle; position delay, 0.3 s; injection speed, 420 μL/s for both pumps 1 and 2.

The final ORAC$_{FL}$ values were calculated by using a quadratic regression equation ($y = ax^2 + bx + c$) between the Trolox or sample concentration and net area under the FL decay curve. Data are expressed as micromoles of Trolox equivalents (TE) per gram or per milliliter of sample (μmol of TE/g or μmol of TE/mL). The area under curve (AUC) was calculated as

$$\text{AUC} = (\,0.5 + f_5/f_4 + f_6/f_4 + f_7/f_4 + ... + f_{34}/f_4 + f_{35}/f_4) \times \text{CT}$$

where f_4 = fluorescence reading at cycle 4, f_i = fluorescence reading at cycle i, and CT = cycle time in minutes.

The data were analyzed using a Microsoft Excel (Microsoft, Redmond, WA) spreadsheet.

Lipophilic and Hydrophilic ORAC$_{FL}$ Assay of Samples. Lipophilic and hydrophilic ORAC$_{FL}$ assays were based on the method described previously (*28*). All data were expressed as micromoles of Trolox equivalents per gram or milliliter (μmol of TE/g for solid food or μmol of TE/mL for liquid food). For each specific sample, duplicate extractions were performed and used for analyses.

Lipophilic (L-ORAC$_{FL}$) and hydrophilic ORAC$_{FL}$ values (H-ORAC$_{FL}$) were measured separately on most common foods in U.S. markets. Total antioxidant capacity (TAC) was calculated by summing the L-ORAC$_{FL}$ and H-ORAC$_{FL}$. For foods without L-ORAC$_{FL}$ data, TAC was estimated using H-ORAC$_{FL}$ because for most foods, H-ORAC$_{FL}$ contributed >90% of their TAC. For fresh fruit and vegetable samples, their freeze-dried forms were used for testing, and then the data were converted to a fresh weight (FW) basis based upon a dry matter analysis on the fresh sample. All other samples were analyzed in their original form. The data (**Tables 1**−**7**) are all expressed on the basis of the usual form of consumption of the foods.

Total Phenolics Analysis. The TP analysis was based on the Folin−Ciocalteu method (*33*). Gallic acid calibration solutions (100, 80, 60, 40, and 20 mg/dL) were made and run on the Analette analyzer to obtain a standard curve. The TP of food samples were performed on the AWA extracts and were calculated on the basis of the standard curve for gallic acid. The results were expressed as milligrams of gallic acid equivalents per gram or milliliter (mg of GAE/g or mg of GAE/mL).

Statistics. Descriptive statistical analysis was performed using Microsoft Excel and/or SigmaStat version 2.03 (Systat Software, Inc., Point Richmond, CA). The data were expressed as means ± standard deviation (SD) for foods having sample numbers >2.

RESULTS AND DISCUSSION

Measurement of Antioxidant Capacity. More and more evidence has indicated that it may be whole fruits or vegetables, rather than certain individual compounds they contain, that may be responsible for many of the health effects observed in epidemiological studies. To evaluate the antioxidant capacities of foods, numerous in vitro methods have been developed. However, there has not been a consensus as to the preferred method or methods. ORAC, Trolox equivalent antioxidant capacity (TEAC), total radical-trapping antioxidant parameter (TRAP), and ferric-reducing ability of plasma (FRAP) are among the more popular methods that have been used. The merits and disadvantages of these methods have been fully discussed in several reviews (*24*, *25*, *34*, *35*).

Recently, some fairly large-scale analyses were done to evaluate the antioxidant capacity of foods (*36*−*39*). Unfortunately, the methods used in most of these studies were different. We observed early on (*40*) that the radical source used in the assay can have dramatic effects on the antioxidant capacity observed because of the differential response of different types of antioxidant compounds to the radical source. Because of this variation, the use of radical sources that are relevant to human biology becomes important in analyzed food sources. The peroxyl radical is the most common free radical in human biology, but the hydroxyl radical, singlet oxygen, superoxide radical, and reactive nitrogen species all are present in biological systems. However, in some methods used to assess food antioxidant capacity (*36*, *39*), radicals that are foreign to biology have been used [i.e., 2,2-di(4-*tert*-octylphenyl)-1-picrylhydrazyl (DPPH) and 2,2′-azinobis(3-ethylbenzthiazoline-6-sulfonic acid) (ABTS)]. DPPH is a stable organic nitrogen radical, which bears no similarity to the highly reactive and transient peroxyl radicals involved in various oxidative reactions in vivo. ABTS$^{\bullet+}$, which is used in the TEAC assay, does not measure the radical scavenging activity of a sample but simply measures a sample's ability to reduce ABTS$^{\bullet+}$. Similarly, the FRAP assay (*37*−*39*) takes advantage of electron transfer using a ferric salt with a redox potential similar to that of ABTS$^{\bullet+}$. Thus, there is not much difference between the TEAC and FRAP assays. The TRAP assay (*39*) uses a peroxyl radical generator similar to ORAC, but calculations are based only upon the observed lag phase rather than the area under the curve method as is used in the ORAC assay. This presents problems in calculations as some pure compounds or foods do not have a distinct lag phase unless assayed at relatively high concentrations. Thus, it is not surprising to see the different ranking order of antioxidant capacity of different foods from ORAC$_{FL}$ compared to published data using other methods. Better measurement and understanding of total antioxidant capacity may be very helpful in studies of relationships of dietary factors and disease prevention. However, one should keep in mind that total antioxidant capacity, as measured by ORAC$_{FL}$ or any other in vitro methods, may not reflect in vivo antioxidant effects. Many other issues such as absorption/metabolism and physicochemical properties of different antioxidants are also very important.

Reproducibility Test of the ORAC$_{FL}$ Assay. The ruggedness of the ORAC$_{FL}$ assay using hydrophilic and lipophilic extracts of blueberry was tested over the time period in which we analyzed all samples with one analysis each week. For the hydrophilic ORAC$_{FL}$ assay, the mean ± SD was 553.4 ± 19.3 μmol of TE/g of dry weight (DW), CV = 3.5%; for the lipophilic ORAC$_{FL}$ assay, the mean ± SD was 4.27 ± 0.38 μmol of TE/g of DW, CV = 8.9%.

Sample Preparation Method. Sample preparation was another crucial issue in this study. Extraction methods, solvents used, extraction temperature, and processing after extraction are factors that may dramatically influence the final results. In our preliminary study (*28*), several factors that may affect the final results were discussed. The methods used for sample preparation and extraction in this study were found to be appropriate to separate lipophilic and hydrophilic components.

Sources of Variation in Antioxidant Capacity of Foods. It is known that genetics, harvest season, and geographic and environmental conditions may significantly influence the content of plant secondary metabolites. Most samples in our present study were collected from U.S. markets in four different regions

Table 1. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity (TAC), and Total Phenolics (TP) of Fruits[a]

food name (variety)	moisture (%)	L-ORAC$_{FL}$[b] (μmol of TE/g)	range[c]	H-ORAC$_{FL}$ (μmol of TE/g)	range[c]	TAC[d] (μmol of TE/g)	TP[e] (mg of GAE/g)	serving size[f] (g)	TAC/serving (μmol of TE)
apples									
Fuji ($n = 4$[g])	84.2	0.21 ± 0.11	0.25	25.72 ± 6.96	16.45	25.93	2.11 ± 0.32	138 (1 fruit)	3578
Gala ($n = 3$)	85.8	0.35 ± 0.08	0.15	27.93 ± 1.42	2.78	28.28	2.62 ± 0.29	138 (1 fruit)	3903
Golden Delicious (peel, $n = 4$)	86.1	0.26 ± 0.06	0.13	26.44 ± 1.61	3.58	26.70	2.48 ± 0.18	138 (1 fruit)	3685
Golden Delicious (no peel, $n = 2$)	86.9	0.05	0.03	22.05	5.25	22.10	2.17	128 (1 fruit)	2829
Granny Smith ($n = 4$)	85.7	0.39 ± 0.11	0.23	38.60 ± 4.69	9.72	38.99	3.41 ± 0.38	138 (1 fruit)	5381
Red Delicious (peel, $n = 4$)	85.5	0.41 ± 0.02	0.04	42.34 ± 4.08	9.25	42.75	3.47 ± 0.38	138 (1 fruit)	5900
Red Delicious (no peel, $n = 2$)	86.7	0.07	0.003	29.29	6.73	29.36	2.32	128 (1 fruit)	3758
apricot ($n = 1$)	86.5	0.32	N/C[h]	13.09	N/C	13.41	1.33	105 (3 fruits)	1408
avocado, Haas ($n = 8$)	72.0	5.52 ± 1.85	5.21	13.81 ± 3.58	10.88	19.33	1.87 ± 0.23	173 (1 fruit)	3344
bananas ($n = 4$)	73.5	0.66 ± 0.14	0.32	8.13 ± 1.02	2.38	8.79	2.31 ± 0.60	118 (1 fruit)	1037
blackberry ($n = 4$)	86.9	1.03 ± 0.32	0.62	52.45 ± 8.94	19.47	53.48	6.60 ± 2.85	144 (1 c[i])	7701
blueberry									
cultivated ($n = 8$)	85.0	0.36 ± 0.18	0.52	61.84 ± 7.75	24.27	62.20	5.31 ± 0.96	145 (1 c)	9019
lowbush ($n = 1$)	89.0	0.51	N/C	92.09	N/C	92.60	7.95	145 (1 c)	13427
cantaloupe ($n = 7$)	90.3	0.15 ± 0.08	0.18	2.97 ± 0.62	1.64	3.12	1.24 ± 0.19	160 (1 c cubed)	499
cherries, sweet ($n = 4$)	80.2	0.17 ± 0.12	0.24	33.44 ± 3.43	7.18	33.61	3.39 ± 0.41	145 (1 c)	4873
cranberry ($n = 3$)	87.1	2.00 ± 0.38	0.72	92.56 ± 1.38	2.42	94.56	7.09 ± 0.07	95 (1 c whole)	8983
grapes									
green ($n = 4$)	80.7	N/A[j]	N/C	11.18 ± 1.66	3.98	11.18	1.45 ± 0.11	160 (1 c)	1789
red ($n = 4$)	80.4	N/A	N/C	12.60 ± 3.17	6.62	12.60	1.75 ± 0.17	160 (1 c)	2016
grapefruit, red ($n = 8$)	88.8	0.35 ± 0.10	0.35	15.13 ± 3.36	9.09	15.48	2.14 ± 0.33	123 (half)	1904
honeydew ($n = 8$)	90.6	0.11 ± 0.05	0.15	2.30 ± 0.92	2.58	2.41	0.72 ± 0.34	170 (1 c diced)	410
kiwifruit ($n = 9$)	84.0	0.27 ± 0.14	0.30	8.91 ± 2.04	5.67	9.18	2.78 ± 0.39	76 (1 fruit)	698
mango ($n = 1$)	81.7	0.14	N/C	9.88	N/C	10.02	2.66	165 (1 c slices)	1653
nectarines ($n = 8$)	86.8	0.29 ± 0.21	0.50	7.20 ± 2.62	7.51	7.49	1.07 ± 0.26	136 (1 fruit)	1019
orange, navel ($n = 8$)	86.8	0.29 ± 0.13	0.35	17.85 ± 3.79	9.76	18.14	3.37 ± 0.39	140 (1 fruit)	2540
peaches									
canned in heavy syrup ($n = 4$)	N/A	N/A	N/C	4.19 ± 0.40	0.91	4.19	0.47 ± 0.03	98 (half)	411
peaches ($n = 8$)	88.3	0.50 ± 0.07	0.17	18.13 ± 4.35	12.77	18.63	1.63 ± 0.29	98 (1 fruit)	1826
pears									
green cultivars ($n = 7$)	83.1	0.56 ± 0.15	0.40	18.56 ± 2.53	6.92	19.11	2.20 ± 0.18	166 (1 fruit)	3172
Red Anjou ($n = 4$)	83.1	0.35 ± 0.03	0.08	17.38 ± 3.45	7.67	17.73	2.18 ± 0.33	166 (1 fruit)	2943
pineapples ($n = 10$)	86.8	0.29 ± 0.15	0.50	7.64 ± 2.12	6.49	7.93	1.74 ± 0.52	155 (1 c diced)	1229
plums									
plums ($n = 8$)	87.4	0.17 ± 0.10	0.24	62.22 ± 20.22	59.18	62.39	3.66 ± 1.09	66 (1 fruit)	4118
plums, black ($n = 2$)	87.9	0.38	0.16	73.01	14.67	73.39	4.78	66 (1 fruit)	4844
raspberry ($n = 6$)	85.8	1.60 ± 0.66	1.65	47.65 ± 7.18	20.47	49.25	5.04 ± 0.84	123 (1 c)	6058
strawberry ($n = 8$)	91.1	0.36 ± 0.25	0.61	35.41 ± 4.24	12.51	35.77	3.68 ± 0.80	166 (1 c)	5938
tangerines ($n = 4$)	85.8	0.07 ± 0.01	0.03	16.13 ± 3.44	7.90	16.20	1.92 ± 0.33	84 (1 fruit)	1361
watermelons ($n = 6$)	92.1	0.19 ± 0.04	0.12	1.23 ± 0.17	0.46	1.42	0.59 ± 0.14	152 (1 c diced)	216

[a] Data expressed on the "as is" weight basis and presented as mean ± SD for sample numbers >2. [b] ORAC$_{FL}$ data expressed as micromoles of Trolox equivalents per gram (μmol of TE/g). [c] Range defined as the difference between the maximum and minimum values observed. [d] TAC = L-ORAC$_{FL}$ + H-ORAC$_{FL}$. For foods without L-ORAC$_{FL}$, H-ORAC$_{FL}$ was used. [e] Total phenolics data expressed as milligrams of gallic acid equivalents per gram (mg of GAE/g). [f] Serving size from the USDA National Nutrient Database for Standard Reference (www.nal.usda.gov/fnic/foodcomp). [g] Sample number for each food. [h] Not calculated. [i] Cup. [j] Not available.

and in two different seasons, giving a broad sample base from which the analytical values were derived. In our previous paper (*28*), we have shown that for some foods, variations from the two sampling times (pass 1 versus pass 2) were significant. In this paper, the impact of time of year and location on the values obtained is reflected in the ranges given for each food for lipophilic and hydrophilic ORAC$_{FL}$ (**Tables 1−4**). Due to limitations of the sampling scheme, it was not possible to identify the specific causes of this variation, but variety and growing conditions (i.e., climate, location, temperature, fertility, disease and pest exposure, etc.) can have major effects. At some times of the year in some markets, the foods available in the United States are likely produced and imported from other countries. Thus, the strength of these data is that the sampling protocol attempted to take into account the potential variation that might exist in the U.S. market and reflect the average consumption by the consumer. For all foods for which we have data, the average values of samples from the two different seasons and four different sampling regions are presented.

ORAC$_{FL}$ of Fruits and Vegetables. L-ORAC$_{FL}$, H-ORAC$_{FL}$, and TAC of fruits and vegetables are presented in **Tables 1** and **2**. There are 24 fruits and 22 vegetables that were analyzed. ORAC$_{FL}$ values of fruits and vegetables are generally higher than values reported previously (*40−42*) because of the use of fluorescein compared to phycoerythrin as the fluorescent probe.

The range of H-ORAC$_{FL}$ was large among the different fruits (**Table 1**). Of all the fruit samples, berries, plums, and some varieties of apples have a relatively high H-ORAC$_{FL}$, with cranberry and lowbush blueberry having the highest H-ORAC$_{FL}$. H-ORAC$_{FL}$ for all of the melons was relatively low. It is noteworthy that those fruit samples with high H-ORAC$_{FL}$ also had high anthocyanin content (*43*), which is in agreement with previous studies (*42*, *44*).

The range of H-ORAC$_{FL}$ in fresh vegetables was not as great as that among fruits (**Table 2**). Most values were in a range from 5 to 20 μmol of TE/g of FW. Of the fresh vegetables assayed, cooked artichoke had an extremely high H-ORAC$_{FL}$ compared to all other vegetables including the fresh and cooked forms, and cucumber had the lowest value. The H-ORAC$_{FL}$ of "baby carrot" was about one-third that of "regular" carrots. The difference appears to be a variety difference as preparation of the samples for analysis was similar. The baby carrots were cut in half and composited. The regular carrots were peeled, and 1 in. was removed from the top and bottom.

Five dried bean samples and one dried pea sample are also included in **Table 2**. These samples had high H-ORAC$_{FL}$. It is

Table 2. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity (TAC), and Total Phenolics (TP) of Vegetables[a]

food name (variety)	moisture (%)	L-ORAC$_{FL}$[b] (μmol of TE/g)	range	H-ORAC$_{FL}$ (μmol of TE/g)	range	TAC[c] (μmol of TE/g)	TP[d] (mg of GAE/g)	serving size[e] (g)	TAC/serving (μmol of TE)
artichoke (C,[f] $n = 2$[g])	86.9	1.32	1.25	92.77	1.11	94.09	7.92	84 (1 c,[i] hearts)	7904
asparagus									
(R,[j] $n = 4$)	92.7	1.02 ± 0.18	0.44	29.15 ± 2.20	5.44	30.17	1.41 ± 0.03	67 ($^1/_2$ c)	2021
(C, $n = 4$)	N/C[h]	N/A[k]	N/C	16.44 ± 2.47	7.42	16.44	1.59 ± 0.13	90 ($^1/_2$ c)	1480
beans									
lima (Can,[l] $n = 1$)	71.4	0.27	N/C	2.15	N/C	2.43	0.96	124 ($^1/_2$ c)	301
snap (R, $n = 1$)	92.8	0.55	N/C	2.13	N/C	2.67	0.92	55 ($^1/_2$ c)	147
snap (Can, $n = 1$)	93.3	0.84	N/C	2.06	N/C	2.90	0.61	68 ($^1/_2$ c)	197
beans, dry, mature									
black (D,[m] $n = 1$)	N/C	4.47	N/C	75.93	N/C	80.40	8.80	52 ($^1/_2$ c)	4181
navy (D, $n = 1$)	N/C	4.54	N/C	20.19	N/C	24.74	2.23	104 ($^1/_2$ c)	2573
pinto (D, $n = 3$)	N/C	4.22 ± 0.14	0.28	119.37 ± 4.57	7.92	123.59	10.23 ± 0.27	96 ($^1/_2$ c)	11864
red kidney (D, $n = 1$)	N/C	0.09	N/C	144.04	N/C	144.13	12.47	92 ($^1/_2$ c)	13259
small red (D, $n = 1$)	N/C	3.82	N/C	145.39	N/C	149.21	11.85	92 ($^1/_2$ c)	13727
beets (R, $n = 1$)	88.1	0.09	N/C	27.65	N/C	27.74	2.44	68 ($^1/_2$ c)	1886
broccoli									
(R, $n = 8$)	90.8	1.72 ± 0.24	0.61	14.18 ± 2.04	6.01	15.90	3.37 ± 0.62	44 ($^1/_2$ c)	700
(C, $n = 4$)	N/C	0.33 ± 0.10	0.15	12.26 ± 2.22	8.47	12.59	3.26 ± 1.70	78 ($^1/_2$ c)	982
raab (R, $n = 2$)	91.2	2.74	0.01	28.10	12.14	30.84	3.66	85 ($^1/_5$ bunch)	2621
raab (C, $n = 4$)	N/C	0.70 ± 0.23	0.23	14.85 ± 1.67	5.21	15.55	2.84 ± 0.21	85 ($^1/_5$ bunch)	1322
cabbages									
common (R, $n = 4$)	91.3	0.20 ± 0.05	0.09	13.39 ± 1.58	3.46	13.59	2.03 ± 0.31	35 ($^1/_2$ c)	476
red (R, $n = 4$)	91.0	0.20 ± 0.14	0.30	22.32 ± 3.68	7.74	22.52	2.54 ± 0.18	35 ($^1/_2$ c)	788
red (C, $n = 4$)	N/C	N/A	N/C	31.46 ± 6.00	14.31	31.46	3.21 ± 0.57	75 ($^1/_2$ c)	2359
carrots									
(R, $n = 4$)	88.7	0.59 ± 0.14	0.33	11.56 ± 1.79	4.21	12.15	1.25 ± 0.10	61 (1 medium)	741
(C, $n = 4$)	N/C	0.15 ± 0.10	0.24	3.56 ± 0.69	1.69	3.71	1.56 ± 0.28	46 (1 carrot)	171
baby (R, $n = 7$)	90.4	0.81 ± 0.22	0.59	3.55 ± 1.48	4.61	4.36	0.45 ± 0.14	60 (6 medium)	262
cauliflower (R, $n = 1$)	92.5	0.37	N/C	6.10	N/C	6.47	2.74	50 ($^1/_2$ c)	324
celery (R, $n = 8$)	95.3	0.41 ± 0.07	0.20	5.33 ± 2.05	4.77	5.74	0.56 ± 0.21	60 ($^1/_2$ c dice)	344
corn									
(R, $n = 1$)	78.1	1.35	N/C	5.93	N/C	7.28	2.11	77 ($^1/_2$ c)	561
(Fro,[n] $n = 1$)	74.3	0.75	N/C	4.47	N/C	5.22	1.74	82 ($^1/_2$ c)	428
(Can, $n = 1$)	77.7	0.52	N/C	3.61	N/C	4.13	1.69	105 ($^1/_2$ c)	434
cucumber									
peel, $n = 4$	96.4	0.28 ± 0.03	0.07	0.87 ± 0.18	0.42	1.15	0.27 ± 0.05	52 ($^1/_2$ c, slices)	60
no peel, $n = 4$	97.2	0.11 ± 0.05	0.08	1.12 ± 0.25	0.61	1.23	0.24 ± 0.05	60 ($^1/_2$ c)	74
eggplant (R, $n = 1$)	91.8	0.24	N/C	25.09	N/C	25.33	2.52	41 ($^1/_2$ c)	1039
lettuces									
butterhead (R, $n = 8$)	95.6	1.03 ± 0.52	1.65	13.21 ± 10.77	33.02	14.24	1.00 ± 0.57	30 (4 leaves)	427
green leaf (R, $n = 8$)	95.0	1.41 ± 0.26	0.72	14.09 ± 4.06	11.83	15.50	1.31 ± 0.39	40 (4 leaves)	620
iceberg (R, $n = 7$)	96.0	0.33 ± 0.10	0.30	4.18 ± 2.80	6.17	4.51	0.50 ± 0.28	32 (4 leaves)	144
red leaf (R, $n = 8$)	95.6	1.35 ± 0.24	0.74	16.50 ± 4.77	12.27	17.85	1.14 ± 0.26	68 (4 outer leaves)	1213
romaine (R, $n = 8$)	94.8	1.62 ± 0.58	1.94	8.27 ± 2.94	8.63	9.89	0.78 ± 0.30	40 (4 inner leaves)	396
onions									
yellow (R, $n = 4$)	91.0	0.12 ± 0.03	0.06	10.17 ± 1.89	6.29	10.29	0.91 ± 0.09	80 ($^1/_2$ c)	823
yellow (C, $n = 4$)	N/C	N/A	N/C	12.20 ± 1.71	3.98	12.20	1.50 ± 0.47	105 ($^1/_2$ c)	1281
sweet (R, $n = 8$)	91.1	0.21 ± 0.09	0.28	5.94 ± 0.74	2.04	6.15	0.74 ± 0.20	80 ($^1/_2$ c)	492
red (R, $n = 1$)	87.7	0.11	N/C	11.35	N/C	11.46	1.26	80 ($^1/_2$ c)	917
peas									
blackeye (D, $n = 1$)	N/C	6.36	N/C	37.07	N/C	43.43	6.47	52 ($^1/_2$ c)	2258
green (Fro, $n = 1$)	78.5	0.95	N/C	5.05	N/C	6.00	1.87	80 ($^1/_2$ c)	480
green (Can, $n = 1$)	82.2	0.80	N/C	3.04	N/C	3.84	1.66	85 ($^1/_2$ c)	326
peppers									
green, sweet (R, $n = 4$)	94.7	0.14 ± 0.03	0.06	5.44 ± 1.21	2.93	5.58	2.71 ± 0.36	119 (1 pepper)	664
green, sweet (C, $n = 4$)	N/C	N/A	N/C	6.15 ± 1.64	3.36	6.15	4.37 ± 1.08	68 ($^1/_2$ c, chopped)	418
red, sweet (R, $n = 4$)	92.2	0.24 ± 0.11	0.23	8.77 ± 1.51	3.46	9.01	4.24 ± 0.76	119 (1 pepper)	1072
red, sweet (C, $n = 4$)	N/C	N/A	N/C	8.47 ± 1.79	4.06	8.47	5.64 ± 1.08	68 ($^1/_2$ c, chopped)	576
orange, sweet (R, $n = 1$)	90.2	0.76	N/C	9.08	N/C	9.84	5.43	186 (1 pepper)	1830
yellow (R, $n = 1$)	90.1	0.69	N/C	9.56	N/C	10.24	5.66	186 (1 pepper)	1905
potatoes									
red (R, $n = 4$)	80.9	0.38 ± 0.01	0.03	10.60 ± 1.34	3.07	10.98	1.38 ± 0.29	213 (1 potato)	2339
red (C, $n = 8$)	N/C	0.22 ± 0.08	0.24	13.04 ± 1.79	3.68	13.26	1.76 ± 0.16	173 (1 potato)	2294
russet (R, $n = 4$)	78.9	0.51 ± 0.14	0.31	12.72 ± 2.28	5.26	13.23	1.22 ± 0.23	369 (1 potato)	4882
russet (C, $n = 4$)	N/C	0.28 ± 0.09	0.26	15.27 ± 1.33	5.07	15.55	1.79 ± 0.57	299 (1 potato)	4649
white (R, $n = 3$)	81.7	0.49 ± 0.12	0.25	10.10 ± 2.12	4.16	10.59	1.63 ± 0.17	213 (1 potato)	2257
white (C, $n = 3$)	N/C	0.40 ± 0.28	0.65	10.41 ± 1.90	4.57	10.81	1.36 ± 0.60	173 (1 potato)	1870
pumpkin (R, $n = 1$)	89.9	0.69	N/C	4.14	N/C	4.83	1.57	116 (1 c, 1-in. cubes)	560
radishes ($n = 7$)	95.6	0.26 ± 0.12	0.34	9.28 ± 1.31	3.72	9.54	1.10 ± 0.28	116 (1 c, sliced)	1107
spinach (R, $n = 1$)	90.0	4.20	N/C	22.20	N/C	26.40	2.17	40 (4 leaves)	1056
sweet potatoes									
(R, $n = 4$)	77.5	0.44 ± 0.11	0.27	8.58 ± 1.15	2.65	9.02	0.74 ± 0.27	130 (1 potato)	1173
(C, $n = 4$)	N/C	0.37 ± 0.31	0.68	7.29 ± 2.04	4.78	7.66	1.20 ± 0.28	156 (1 potato)	1195
tomatoes									
(R, $n = 7$)	94.9	0.24 ± 0.07	0.16	3.13 ± 0.69	2.09	3.37	0.80 ± 0.12	123 (1 tomato)	415
(C, $n = 4$)	93.6	0.34 ± 0.05	0.14	4.26 ± 0.86	1.92	4.60	1.00 ± 0.11	120 ($^1/_2$ c)	552

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[a] Data expressed on the "as is" weight basis and presented as mean ± SD for sample numbers >2. [b] ORAC$_{FL}$ data expressed as micromoles of Trolox equivalents per gram (μmol of TE/g). [c] TAC = L-ORAC$_{FL}$ + H-ORAC$_{FL}$. For foods without L-ORAC$_{FL}$, H-ORAC$_{FL}$ was used. [d] Total phenolics data expressed as milligrams of gallic acid equivalents per gram (mg of GAE/g). [e] Serving size from USDA National Nutrient Database for Standard Reference (www.nal.usda.gov/fnic/foodcomp). [f] C, cooked. [g] Sample number for each food. [h] N/C, not calculated. [i] c, cup. [j] R, raw. [k] N/A, not available. [l] Can, canned. [m] D, dried. [n] Fro, frozen.

Table 3. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity (TAC), and Total Phenolics (TP) of Nuts[a]

nut	L-ORAC$_{FL}$[b] (μmol of TE/g)	range	H-ORAC$_{FL}$ (μmol of TE/g)	range	TAC[c] (μmol of TE/g)	TP[d] (mg of GAE/g)	serving size[e] (g)	TAC/serving (μmol of TE)
almonds ($n = 8$[f])	1.72 ± 0.50	1.48	42.82 ± 8.71	25.62	44.54	4.18 ± 0.84	28.4 (1 oz)	1265
Brazil nuts ($n = 6$)	5.57 ± 2.17	5.42	8.62 ± 2.06	5.72	14.19	3.10 ± 0.96	28.4 (1 oz)	403
cashews ($n = 7$)	4.74 ± 1.38	3.94	15.23 ± 2.04	5.49	19.97	2.74 ± 0.39	28.4 (1 oz)	567
hazelnuts ($n = 8$)	3.70 ± 2.66	7.74	92.75 ± 17.78	61.60	96.45	8.35 ± 2.16	28.4 (1 oz)	2739
macadamias ($n = 8$)	2.52 ± 0.57	1.59	14.43 ± 2.31	7.59	16.95	1.56 ± 0.29	28.4 (1 oz)	481
peanuts ($n = 4$)	2.73 ± 1.04	2.25	28.93 ± 2.36	4.93	31.66	3.96 ± 0.54	28.4 (1 oz)	899
pecans ($n = 8$)	4.16 ± 0.98	3.22	175.24 ± 10.36	30.76	179.40	20.16 ± 1.03	28.4 (1 oz)	5095
pine nuts ($n = 8$)	2.76 ± 0.60	1.48	4.43 ± 1.11	3.58	7.19	0.68 ± 0.25	28.4 (1 oz)	204
pistachios ($n = 7$)	4.25 ± 1.46	4.18	75.57 ± 10.50	30.60	79.83	16.57 ± 1.21	28.4 (1 oz)	2267
walnuts ($n = 8$)	4.84 ± 1.25	3.21	130.57 ± 35.20	95.20	135.41	15.56 ± 4.06	28.4 (1 oz)	3846

[a] Data expressed on the "as is" weight bais and presented as mean ± SD for sample numbers >2. [b] ORAC$_{FL}$ data expressed as micromoles of Trolox equivalents per gram (μmol of TE/g). [c] TAC = L-ORAC$_{FL}$ + H-ORAC$_{FL}$. [d] Total phenolics data expressed as milligrams of gallic acid equivalents per gram (mg of GAE/g). [e] Serving size from USDA National Nutrient Database for Standard Reference (www.nal.usda.gov/fnic/foodcomp). [f] Sample number for each food.

Table 4. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity (TAC), and Total Phenolics (TP) of Dried Fruits (Expressed on "As Consumed" Weight Basis)[a]

food	moisture (%)	L-ORAC$_{FL}$[b] (μmol of TE/g)	range	H-ORAC$_{FL}$ (μmol TE/g)	range	TAC[c] (μmol of TE/g)	TP[d] (mg of GAE/g)	serving size[e] (g)	TAC/serving (μmol of TE)
dates									
Deglet Noor ($n = 7$[f])	20.0	0.32 ± 0.16	0.32	38.63 ± 3.21	9.35	38.95	6.61 ± 1.11	89 (1/2 c[g])	3467
Medjool ($n = 2$)	21.3	0.27	0.13	23.60	6.32	23.87	5.72	89 (1/2 c)	2124
figs ($n = 7$)	30.1	1.83 ± 0.13	0.99	32.00 ± 3.31	15.00	33.83	9.60 ± 0.07	75 (1/2 c)	2537
prunes ($n = 8$)	32.7	1.79 ± 0.56	1.44	83.99 ± 16.56	46.36	85.78	11.95 ± 1.56	85 (1/2 c)	7291
raisins ($n = 8$)	17.7	0.35 ± 0.13	0.36	30.02 ± 5.23	17.28	30.37	10.65 ± 1.59	82 (1/2 c)	2490

[a] Data presented as mean ± SD for sample numbers >2. [b] ORAC$_{FL}$ data expressed as micromoles Trolox equivalents per gram (μmol of TE/g). [c] TAC = L-ORAC$_{FL}$ + H-ORAC$_{FL}$. [d] Total phenolics data expressed as milligrams of gallic acid equivalents per gram (mg of GAE/g). [e] Serving size from USDA National Nutrient Database for Standard Reference (www.nal.usda.gov/fnic/foodcomp). [f] Sample number for each food. [g] c, cup.

important to note that all of these data for beans and peas in the table are expressed on the basis of the dried forms.

Compared to H-ORAC$_{FL}$ in fruits and vegetables, the L-ORAC$_{FL}$ values were generally low (**Tables 1** and **2**). For fruits, the highest value observed in all of the samples was for avocado (5.52 μmol of TE/g of FW) and the lowest one for tangerines, with a value of 0.07 μmol of TE/g of FW. Avocado contains monounstaturated fatty acids such as linoleic acid (*45*) and vitamin E, but which lipophilic constituents contribute to the high lipophilic antioxidant capacity is largely unknown. L-ORAC$_{FL}$ values of three berry samples (cranberry, raspberry, and blackberry) were >1 μmol of TE/g of FW, which was higher than those of other berry samples with similar H-ORAC$_{FL}$. For vegetables, spinach had a relatively high L-ORAC$_{FL}$ compared to other fresh vegetables. Except for the dried beans and peas, L-ORAC$_{FL}$ of four specific vegetables [spinach, broccoli, asparagus, and lettuce (excluding the iceberg variety)] was higher than that of others. It is noteworthy that all of them are dark green in color, indicating that the green pigments or lipophilic components associated with these pigments in these samples may be responsible for their higher L-ORAC$_{FL}$.

Total antioxidant capacity (TAC) paralleled H-ORAC$_{FL}$ in most fruits and vegetables because hydrophilic ORAC made up ≥90% of the total antioxidant capacity. The fruit and vegetable with highest total ORAC were cranberry (94.6 μmol of TE/g of FW) and broccoli raab (30.8 μmol of TE/g of FW), respectively (**Tables 1** and **2**).

ORAC$_{FL}$ of Nuts. Almost all of the common nuts in the U.S. market were included in our sample list. Their L-ORAC$_{FL}$, H-ORAC$_{FL}$, and TAC are shown in **Table 3**. Variation of H-ORAC$_{FL}$ among different nuts is quite large, ranging from the lowest for pine nut (4.43 μmol of TE/g) to the highest for pecan (175.2 μmol of TE/g). The range of L-ORAC$_{FL}$ in nuts is not as large as that of H-ORAC$_{FL}$. Nuts are an important source of dietary lipids and have been suggested as a potential source of dietary antioxidants on the basis of recent epidemiological and cohort studies (*46*−*48*). One interesting feature in this group of foods is that for some samples, H-ORAC$_{FL}$ was not as predominant a component of TAC as for fruits and vegetables (i.e., H-ORAC$_{FL}$ of Brazil nuts and pine nuts made up only 60.7 and 61.6% of TAC, respectively).

ORAC$_{FL}$ of Dried Fruits. Four dried fruits were analyzed (**Table 4**). H-ORAC$_{FL}$ and TAC of figs, raisins, and dates were ∼30 μmol of TE/g, whereas those of prunes were nearly 3 times higher. Major antioxidant components in prunes are caffeoylquinic acid isomers, which have been shown to have high antioxidant capacity (*49*, *50*). The L-ORAC$_{FL}$ ranged from ∼0.30 to ∼1.8 μmol of TE/g in these dried fruits. The contribution of L-ORAC$_{FL}$ to TAC was similar to that of fresh fruits, which indicated that the drying process did not change the proportion of hydrophilic and lipophilic ORAC$_{FL}$.

ORAC$_{FL}$ of Dried Spices. Probably the most surprising results came from the analyses of the dried spices. ORAC$_{FL}$ values of 16 spices are shown in **Table 5**. Compared to other samples analyzed in this study, some spices had extremely high L-ORAC$_{FL}$ or H-ORAC$_{FL}$. A distinguishing feature of this group of foods is that the L-ORAC$_{FL}$ values of four samples (clove, ginger, black pepper, and turmeric) were higher than their H-ORAC$_{FL}$ values, indicating that the essential oils in them contained considerable quantities of antioxidants. Studies of the bioactivity of spices have focused mainly on their antimicrobial activity (*51*). However, recent studies of antioxidant activity of spices have also been reported (*52*−*54*). The major hydrophilic antioxidants in spices are derivatives of phenolic or cinnamonic acid (*55*). Rosmarinic acid is the main antioxidant constituent

Table 5. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity (TAC), and Total Phenolics (TP) of Spices[a]

food	L-ORAC$_{FL}$[b] (μmol of TE/g)	H-ORAC$_{FL}$ (μmol of TE/g)	TAC[c] (μmol of TE/g)	TP[d] (mg of GAE/g)
basil leaf, dried ($n = 1$[e])	31.14	644.39	675.53	44.89
chili powder ($n = 1$)	18.08	218.27	236.35	17.13
cinnamon, ground ($n = 1$)	34.53	2640.83	2675.36	157.18
cloves, ground ($n = 1$)	1611.37	1533.09	3144.46	113.19
curry powder ($n = 1$)	235.23	249.81	485.04	10.75
garlic powder ($n = 1$)	1.43	65.23	66.66	0.42
ginger, ground ($n = 1$)	218.67	69.44	288.11	3.17
mustard seed, yellow, ground ($n = 1$)	4.98	287.59	292.57	18.44
onion powder ($n = 1$)	0.84	56.51	57.35	8.61
oregano leaf, dried ($n = 1$)	169.88	1831.41	2001.29	72.82
paprika ($n = 1$)	18.23	160.96	179.19	18.66
parsley, dried ($n = 1$)	2.64	740.85	743.49	22.44
pepper, black, ground ($n = 1$)	88.13	162.81	250.94	3.83
pepper, black, whole peppercorn ($n = 1$)	178.96	122.45	301.41	7.11
poppy seed ($n = 1$)	0.75	4.05	4.80	0.20
turmeric ($n = 1$)	1193.46	399.31	1592.77	21.17

[a] Data expressed on “as is” weight basis. [b] ORAC$_{FL}$ data expressed as micromoles of Trolox equivalents per gram (μmol of TE/g). [c] TAC = L-ORAC$_{FL}$ + H-ORAC$_{FL}$. [d] Total phenolics data expressed as milligrams gallic acid equivalents per gram (mg of GAE/g). [e] Sample number for each food.

Table 6. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity (TAC), and Total Phenolics (TP) of Grain-Based Foods[a]

food and brand	L-ORAC$_{FL}$[b] (μmol of TE/g)	H-ORAC$_{FL}$ (μmol of TE/g)	TAC[c] (μmol of TE/g)	TP[d] (mg of GAE/g)	serving size[e] (g)	TAC/serving (μmol of TE)
bread						
($n = 1$[f]), whole grain, HC[g]	1.23	12.98	14.21	1.71	28 (1 slice)	398
Oatnut ($n = 1$), B	0.94	12.24	13.18	1.83	38 (1 slice)	501
pumpernickel ($n = 1$), B	1.28	18.35	19.63	2.71	30 (1 slice)	589
butternut all whole grain wheat ($n = 1$), CH	1.18	19.86	21.04	2.46	28 (1 slice)	589
breakfast cereals, ready to eat						
corn flakes Total ($n = 1$), GM	0.57	23.02	23.59	8.42	30 (1-$^1/_2$ c[h])	708
Life ($n = 1$), Q	0.95	14.22	15.17	1.17	32 ($^3/_4$ c)	485
low-fat granola with raisins ($n = 1$), K	1.26	21.68	22.94	3.67	60 ($^2/_3$ c)	1376
oat bran ($n = 1$), Q	1.17	17.69	18.86	1.63	57 (1-$^1/_4$ c)	1075
Original Shredded Wheat ($n = 1$), P	0.81	12.22	13.03	0.94	49 (1 c)	638
squares toasted oatmeal ($n = 1$), Q	1.30	20.13	21.43	2.71	56 (1 c)	1200
toasted oatmeal ($n = 1$), Q	0.89	20.86	21.75	1.83	49 (1 c)	1066
breakfast cereals, uncooked						
oat bran, hot ($n = 1$), Q	3.06	21.73	24.79	1.71	40 ($^1/_2$ c)	992
instant oatmeal ($n = 1$), Q	2.82	20.26	23.08	1.83	28 (1 packet)	646
oats, quick, 1-min ($n = 1$), Q	4.06	17.63	21.69	1.83	40 ($^1/_2$ c)	868
oats, old-fashioned ($n = 1$), Q	3.06	14.02	17.08	1.63	40 ($^1/_2$ c)	683
snacks						
cookie, oatmeal raisin ($n = 1$), PF	2.80	17.16	19.96	6.38	31 (1 cookie)	619
popcorn, buttered, premium ($n = 1$), PS	2.08	15.35	17.43	1.17	9 (1 c)	157
snack bar, chewy low-fat granola ($n = 1$), Q	2.08	14.66	16.74	2.42	28 (1 bar)	469
snack bar, fruit and oatmeal, strawberry ($n = 1$), Q	2.68	16.95	19.63	2.67	37 (1 bar)	726

[a] Data expressed on “as is” weight basis. [b] ORAC$_{FL}$ data expressed as micromoles of Trolox equivalents per gram (μmol of TE/g). [c] TAC = L-ORAC$_{FL}$ + H-ORAC$_{FL}$. [d] Total phenolics data expressed as milligrams of gallic acid equivalents per gram (mg of GAE/g). [e] Serving size from package label. [f] Sample number for each food. [g] Brands: B, Brownberry; CH, Chicago Baking Co.; GM, General Mills; HC, Healthy Choice, ConAgra; K, Kellogg's; PF, Pepperidge Farm; PS, Pop Secret; P, Post; Q, Quaker. [h] c, cup.

in oregano (*56*). The major lipophilic components in cloves are aroma chemicals such as eugenol, thymol, and benzyl alcohol; eugenol has been shown to have antioxidant activity (*57*). However, the other compounds responsible for these high values of antioxidant capacity are unknown. The primary constituent of cinnamon oil is cinnamic aldehyde, which has been recognized as contributing to cinnamon's antimicrobial activity (*58*). Cinnamon is also rich in proanthocyanidins and phenolic compounds (*59*), which may be responsible for the extremely high H-ORAC$_{FL}$.

Even though spices are an excellent antioxidant source on the basis of their ORAC$_{FL}$ values, it is hard to estimate typical amounts consumed because spices are generally not consumed in large quantities, but as ingredients used in relatively small amounts in recipes and formulations.

ORAC$_{FL}$ of Breakfast and Snack Foods. The ORAC$_{FL}$ values of 19 breakfast cereals, breads, and snack foods are shown in **Table 6**. The range of TAC values among the breakfast cereal samples was not large (13.0−24.8 μmol of TE/g), even in those with high antioxidant capacity ingredients such as strawberries and raisins.

ORAC$_{FL}$ of Other Foods. Other miscellaneous foods, including fruit and vegetable juices, apple sauce, tomato sauce, ketchup, salsa, chocolate milk, chips, chocolate, baby foods, rice bran, and Native American foods (beverage prepared from chilchen berries, blue corn meal, and agave) were also measured (**Table 7**). Because some samples were either in liquid or in paste form, they were not suitable for the accelerated solvent extractor, and thus L-ORAC$_{FL}$ was not determined. Except for some spices, rice bran is the only sample in which the

Table 7. Lipophilic (L-ORAC$_{FL}$), Hydrophilic (H-ORAC$_{FL}$), Total Antioxidant Capacity (TAC), and Total Phenolics (TP) of Other Foods[a]

food	L-ORAC$_{FL}$[b] (μmol of TE/g)	range	H-ORAC$_{FL}$ (μmol of TE/g)	range	TAC[c] (μmol of TE/g)	TP[d] (mg of GAE/g)
apple sauce ($n = 1$[e])	N/A[f]	N/C[g]	19.65	N/C	19.65	2.17
baby foods						
apple blueberry (Gerber) ($n = 1$)	N/A	N/C	48.23	N/C	48.23	5.63
apple sauce (Gerber) ($n = 1$)	N/A	N/C	41.23	N/C	41.23	6.12
bananas (Gerber) ($n = 1$)	N/A	N/C	26.58	N/C	26.58	5.90
peaches (Heinz) ($n = 1$)	N/A	N/C	62.57	N/C	62.57	9.16
pears (Gerber) ($n = 1$)	N/A	N/C	25.51	N/C	25.51	6.73
chips						
Olestra tortilla ($n = 2$)	0.94	0.61	16.09	2.48	17.03	3.04
chocolate						
baking chocolate, ($n = 2$)	7.81	1.14	1031.90	22.64	1039.71	51.46
milk chocolate candy bars ($n = 4$)	10.40 ± 2.51	5.39	71.30 ± 20.49	41.18	81.70	5.07 ± 1.72
Native American foods						
agave (R, $n = 1$)	0.47	N/C	12.01	N/C	12.48	0.87
agave (C, $n = 1$)	1.36	N/C	28.02	N/C	29.38	3.76
agave (D, $n = 1$)	2.50	N/C	70.24	N/C	72.74	13.59
chilchen ($n = 1$)	N/A	N/C	7.40	N/C	7.40	0.11
blue corn meal ($n = 1$)	N/A	N/C	6.84	N/C	6.84	0.77
juices[h]						
grapefruit ($n = 1$)	N/A	N/C	12.92	N/C	12.92	3.51
lemon ($n = 1$)	N/A	N/C	12.63	N/C	12.63	1.80
lime ($n = 4$)	N/A	N/C	8.56 ± 0.49	1.09	8.56	1.22 ± 0.19
tomato ($n = 1$)	N/A	N/C	6.47	N/C	6.47	3.32
V8 vegetable ($n = 1$)	N/A	N/C	5.63	N/C	5.63	2.51
ketchup ($n = 1$)	0.43	N/C	5.35	N/C	5.78	2.49
milk, 2%,[h] chocolate-flavored ($n = 2$)	N/A	N/C	12.63	0.97	12.63	0.59
peanut butter ($n = 3$)	3.05± 0.70	1.35	31.27± 6.15	12.3	34.32	5.36 ± 0.43
rice bran ($n = 1$)	154.70	N/C	88.17	N/C	242.87	6.67
salsa ($n = 1$)	0.35	N/C	9.66	N/C	10.01	2.45
tomato sauce ($n = 1$)	0.42	N/C	6.52	N/C	6.94	1.77

[a] Data expressed on "as is" weight basis and presented as mean ± SD for sample numbers >2. [b] ORAC$_{FL}$ data expressed as micromoles of Trolox equivalents per gram (μmol of TE/g). [c] TAC = L-ORAC$_{FL}$ + H-ORAC$_{FL}$. For foods without L-ORAC$_{FL}$, H-ORAC$_{FL}$ was used. [d] Total phenolics data expressed as milligrams of gallic acid equivalents per gram (mg of GAE/g). [e] Sample number for each food. [f] N/A, not available. [g] N/C, not calculated. [h] ORAC was expressed as micromoles of Trolox equivalents per milliliter (μmol of TE/mL); TP was expressed as milligrams of gallic acid equivalents per milliliter (mg of GAE/mL).

L-ORAC$_{FL}$ is higher than its H-ORAC$_{FL}$. Among all of the other foods, baking chocolate had the highest H-ORAC$_{FL}$ and TAC. The major components in chocolate are proanthocyanidins, which are believed to be largely responsible for its high antioxidant capacity (*60*). However, the ORAC$_{FL}$ value of milk chocolate was much lower, which parallels the much lower proanthocyanidin content (*60*). ORAC$_{FL}$ values of many other common juices have been analyzed by us previously (*32*). Their values ranged from 3.4 μmol of TE/mL (white grape juice) to 32.7 μmol of TE/mL (blueberry juice).

Total Phenolics and the Ratio of H-ORAC$_{FL}$ to Total Phenolics of Food Samples. TP in all samples were analyzed using the Folin–Ciocalteu reagent in the same AWA extracts were used to analyze H-ORAC$_{FL}$. The results of all samples are presented in **Tables 1–6** according to the types of foods. Some studies have demonstrated a linear correlation between the content of total phenolic compounds and antioxidant capacity (*61*). From our current results, we found this may not be true across all types of foods that we analyzed. The H-ORAC$_{FL}$ to TP ratio of raw food samples was ranked into four groups in **Table 8**. This ratio ranged from 1.7 in green pepper to 156.4 in garlic powder. Most foods fell in the range from 5 to 15. If we consider just fruits or vegetables, most of them were close to 10, which indicates a strong positive linear correlation between TP and antioxidant capacity, but if the sampling of foods is extended to a wider range, the H-ORAC$_{FL}$/TP ratio varied greatly. Overall, there is not a high correlation between TP and antioxidant capacity. Thus, measurement of TP alone may not be a good indicator of antioxidant capacity (*62*). From **Table 8**, we can see that samples with high antioxidant capacity tended to have higher H-ORAC$_{FL}$/TP ratios. This may result from the presence of compounds with antioxidant activity that are not "phenolic" or some phenolic compounds being more "effective" than others or having a higher reactivity with the peroxyl free radicals (*63–65*). The chemistry of the peroxyl radical reaction in the ORAC$_{FL}$ assay has been shown to follow a hydrogen atom transfer (HAT) mechanism (*26*). Under normal reaction conditions, phenolic compounds are the predominant antioxidants in hydrophilic extracts of samples that easily transfer one hydrogen to the peroxyl radical (ROO$^\bullet$).

Cooking/Processing Effects on ORAC$_{FL}$. L-ORAC$_{FL}$ and H-ORAC$_{FL}$ of two peeled fruits (Red Delicious and Golden Delicious apples) and one peeled vegetable (cucumber) are presented in **Tables 1** and **2**, respectively. Removal of the peel is one factor that may influence the antioxidant capacity (*28*, *66*) as indicated by lower values in apples compared to that of the intact apple.

Processing of food by cooking can also affect the antioxidant capacity (*67*). Ten vegetables, which normally are consumed in the cooked form, were cooked by the most common methods (baking or boiling in water), and ORAC$_{FL}$ was determined compared to the raw forms (**Table 2**). Cooking significantly influenced antioxidant capacity (*28*). However, the effects were not consistent in different foods. H-ORAC$_{FL}$ values of cooked russet and red potatoes were significantly higher than that of raw forms; however, L-ORAC$_{FL}$ values were significantly lower in the cooked form. There was no significant change in either H-ORAC$_{FL}$ or L-ORAC$_{FL}$ for white potato. Six other samples (broccoli, carrots, tomatoes, asparagus, peppers, and red cabbage) were prepared by boiling. H-ORAC$_{FL}$ and L-ORAC$_{FL}$

Table 8. Foods Categorized into Four Groups Ranked by Their Hydrophilic ORAC to Total Phenolics Ratio (H-ORAC$_{\mathrm{FL}}$/TP)[a]

ratio (H-ORAC$_{\mathrm{FL}}$/TP)	foods
0–5	pepper (1.7[b]); watermelon (2.1); cauliflower (2.2); bean, snap (2.3); cantaloupe (2.4); pumpkin (2.6); corn (2.8); Brazil nut (2.8; raisin (2.8); honeydew (3.2); kiwifruit (3.2); cucumber (3.2); fig (3.3); banana (3.5); mango (3.7); tomato (3.9); broccoli (4.2); pineapple (4.4); pistachio (4.6); date (5.0)
5–10	orange, navel (5.3); cashew (5.6); pea, blackeye (5.7); pine nut (6.5); onion powder (6.6); nectarine (6.7); prune (7.0); grapefruit, red (7.1); peanut (7.3); avocado, Haas (7.4); grape (7.5); cabbage (7.7); carrot, baby (7.9); blackberry (8.0); potato (8.1); pear (8.3); tangerine (8.4); walnut (8.4); radish (8.5); black bean (8.6); paprika (8.6); pecan (8.7); navy bean (9.0); sweet potato (9.0); carrot (9.2); macadamia (9.3); onion (9.4); raspberry (9.5); strawberry (9.6); celery (9.6); apricot (9.9); cherry, sweet (9.9); eggplant (10.0)
10–15	spinach (10.2); almond (10.2); peach (11.1); hazelnut (11.1); beet (11.3); apple (11.4); lettuce (11.5); blueberry (11.6); bean, red kidney (11.6); pinto bean (11.7); bean, small red (12.3); chili powder (12.7); cranberry (13.1); clove, ground (13.5); basil leaf, dried (14.4)
>15	mustard seed, yellow, ground (15.6); plum (16.2); cinnamon, ground (16.8); pepper, black, whole peppercorn (17.2); turmeric (18.9); poppy seed (19.3); asparagus (20.7); ginger, ground (21.9); curry powder (23.2); oregano leaf, dried (25.2); parsley, dried (33.0); pepper, black, ground (42.5); garlic powder (156.4)

[a] Samples are all raw fresh or dry forms; processed foods were not included. For samples with numbers >1 and/or different varieties, mean values were used. [b] Hydrophilic ORAC$_{\mathrm{FL}}$ to total phenolics ratio.

Table 9. Common Foods Categorized into Four Groups Ranked by Their Hydrophilic ORAC$_{\mathrm{FL}}$ (H-ORAC$_{\mathrm{FL}}$) per Serving[a]

H-ORAC$_{\mathrm{FL}}$[b] (μmol of TE/serving)	foods
14000–2000	bean, small red; blueberry, wild; bean, red kidney; bean, pinto; blueberry, cultivated; cranberry; artichoke (C); blackberry; prune; strawberry; raspberry; apple, Red Delicious and Granny Smith; pecan; cherry, sweet; plum, black; potato, russet; potato, russet (C); plum; bean, black; apple, Gala; walnut; apples, Golden Delicious and Fuji; date, Deglet Noor; pear, Green and Red Anjou cultivars; hazelnut; orange, navel; raisin; fig; avocado, Haas; broccoli raab (R); cabbage, red (C); potato, red; potato, red (C); potato, white; pistachio; date, Medjool; bean, navy; grape, red
1999–1000	asparagus; pea, blackeye; beet; grapefruit, red; potato, white (C); grape, green; pepper, yellow; peach; pepper, orange; mango; asparagus, (C); apricot; tangerine; cereal, low-fat granola with raisin (K); onion, yellow (C); broccoli raab (C); almond; pineapple; sweet potato, (C); cereal, squares toasted oatmeal (Q); lettuce, red leaf; sweet potato; radish; pepper, red; eggplant; cereal, toasted oatmeal (Q); cereal, oat bran (Q)
999–500	nectarine; banana; broccoli, (C); onion, red; spinach; cereal, oat bran hot (Q); peanut; onion, yellow; cabbage, red; cereal, oat, quick 1-min (Q); carrot; cereal, corn flakes Total (GM); kiwifruit; pepper, green; snack, fruit and oatmeal, strawberry (Q); broccoli; cereal, Original Shredded Wheat (P); pepper, red (C); cereal, instant oatmeal (Q); lettuce, green leaf; cereal, oats old fashioned (Q); bread, butternut all whole grain wheat; bread, pumpernickel (B); snack, oatmeal raisin cookie (PF); tomato, (C)
499–0	pumpkin; cantaloupe; onion, sweet; cabbage; bread, oatnut (B). corn; cereal, Life (Q); cashews; pepper, green (C); peach, canned; snack, chewy low-fat cranola bar (Q); macadamia; pea, green and frozen; lettuce, butterhead; honeydew; tomato; corn, canned; corn, frozen; bread (HC); lettuce, romaine; celery; cauliflower; bean, lima and canned; pea, green and frozen; Brazil nut; carrot, baby; watermelon; carrot, (C); bean, snap and canned; popcorn, buttered, premium (PS); lettuce, iceberg; pine nuts; bean, snap and fresh; cucumber, peeled and with peel

[a] Foods are listed in order in each group from highest to lowest ORAC value per serving. C, cooked; GM, General Mills; Q, Quaker; P, Post; PF, Pepperidge Farm; PS, Pop Secret; HC, Healthy Choice; B, Brownberry. [b] Hydrophilic ORAC$_{\mathrm{FL}}$, expressed as micromoles of Trolox equivalents per serving (μmol of TE/serving).

significantly decreased in carrots with cooking. Cooked tomatoes had a significantly higher H-ORAC$_{\mathrm{FL}}$ and L-ORAC$_{\mathrm{FL}}$ compared to uncooked samples, which agrees with observations in previous studies (*42*, *68*). In broccoli, there was a significant decrease in L-ORAC$_{\mathrm{FL}}$ but not in H-ORAC$_{\mathrm{FL}}$ in the cooked versus raw forms. Cooked asparagus was significantly lower and red cabbage was significantly higher in H-ORAC$_{\mathrm{FL}}$ compared to the raw forms. Peppers did not show significant changes in H-ORAC$_{\mathrm{FL}}$ with cooking. The different "behavior" of food versus cooking process is directly related with the nature and molecular structures of the respective antioxidant compounds. Our data suggest that foods with active polyphenolic flavonoids are more resistant than foods with vitamins and related compounds. From the limited data on processing effects, it is clear that for a dataset such as this to be complete, additional data will be needed on processed fruits and vegetables, particularly because one cannot predict the effects of processing on any given food.

Hydrophilic and Lipophilic ORAC$_{\mathrm{FL}}$ per Serving in Foods. To make an overall evaluation of the total antioxidant capacity consumed, serving size as well as concentrations must be considered. Foods were assigned a serving size based upon the USDA National Nutrient Database for Standard Reference, release 16 (http://www.nal.usda.gov/fnic/foodcomp) and divided into four groups based upon the ranges of their H-ORAC$_{\mathrm{FL}}$ per serving rather than per weight of food (**Table 9**). These groupings were from 0 to 499, from 500 to 999, from 1000 to 1999, and from 2000 to 14000 μmol of TE, respectively, which is approximately by quartile. Most of the samples in the highest H-ORAC$_{\mathrm{FL}}$ group were fruits, particularly berries. Because

Table 10. Foods Categorized into Four Groups Ranked by Their Lipophilic ORAC$_{FL}$ (L -ORAC$_{FL}$)[a]

L-ORAC$_{FL}$[b] (μmol of TE/serving)	foods
1000–80	avocado, Haas; bean, navy; bean, pinto; bean, small red; pea, blackeye; broccoli raab; bean, black; raspberry; cranberry; potato, russet; spinach; cereal, oat, quick 1-min (Q); Brazil nut; prune; blackberry; pepper, orange; walnut; fig; cashew; pepper, yellow; cereal, oat bran hot (Q); cereal, oats old-fashioned (Q); pistachio; pecan; artichoke (C); hazelnut; potato, white; snack, fruits and oatmeals strawberry (Q); corn, fresh; pear, green cultivars; lettuce, red leaf; snack, oatmeal raisin cookie (PF); potato, russet (C); potato, red; pumpkin
79.9–50	cereal, instant oatmeal (Q); pine nut; banana; peanut; pea, green and frozen; broccoli; cereal, low-fat granola with raisin (K); blueberry, wild; cereal, squares toasted oatmeal (Q); macadamia; potato, white (C); sweet potato; asparagus; pea, green and canned; cereal, oat bran (Q); lettuce, romaine; corn, frozen; strawberry; broccoli raab, (C); snack, chewy low-fat cranola bar (Q); pear, red anjou; dweet potato, (C); bean, snap and canned; apple, red delicious; lettuce, green leaf; corn, canned; apple, Granny Smith; blueberry, cultivated
49.9–30	peach; almond; carrot, baby; apple, gala; pineapple; cereal, toasted oatmeal (Q); grapefruit, red; tomato, (C); orange, navel; cereal, Original Shredded Wheat (P); nectarine; bread, pumpernickel (B); potato, red (C); carrot; apple, Golden Delicious; bread, oatnut (B); bread (HC); apricot; bean, lima and canned; bread, butternut all whole grain wheat; lettuce, butterhead; cereal, Life (Q); bean, snap and fresh; radish
29.9– 0	tomato; apple, Fuji; watermelon; raisin; pepper, red (R); date, Deglet Noor; broccoli, (C); plum, black; cherry, sweet; celery; cantaloupe; mango; kiwifruit; popcorn, buttered, premium (PS); honeydew; cauliflower; cereal, corn flakes Total (GM); onion, sweet; pepper, green; cucumber, with peel; date, Medjool; plum; lettuce, iceberg; eggplant; onion; onion, red; bean, red kidney; cabbage, red; cabbage; carrot, (C); cucumber, without peel; beet; tangerine

[a] Foods are listed in order in each group from highest to lowest ORAC value per serving. C, cooked; GM, General Mills; Q, Quaker; P, Post; PF, Pepperidge Farm; PS, Pop Secret; HC, Healthy Choice; B, Brownberry. [b] Lipophilic ORAC$_{FL}$, expressed as micromoles of Trolox equivalents per serving (μmol of TE/serving).

H-ORAC$_{FL}$ made up most of the TAC, the samples in this group could be regarded as the best sources of total antioxidant capacity. Other samples, such as spices, were not listed because of their small and variable serving size.

These data contribute the first extensive report of the antioxidant capacity of lipophilic components of food samples. Although the L-ORAC$_{FL}$ was relatively low, lipophilic components have different functions and/or sites of action in vivo because of differing physicochemical properties from the hydrophilic components. We divided the foods into four groups based upon their L-ORAC$_{FL}$ (0−29.9, 30−49.9, 50−79.9, and 80−1000 μmol of TE) per serving (**Table 10**). Total L-ORAC$_{FL}$ values per serving of most foods are in the range from 30 to 100 μmol of TE. Spices were not included in this table, although they could be excellent sources of lipophilic antioxidant components.

Estimation of Total Daily ORAC$_{FL}$ Intake of Fruits and Vegetables. Because fruits and vegetables are the major antioxidant sources in our daily diet, estimation of daily antioxidant capacity intake from these foods was calculated. **Table 11** presents an estimation of daily L-ORAC$_{FL}$ and H-ORAC$_{FL}$ intake of common vegetables, fruits, and fruit juices for individuals ages 2 and over in the United States. The data on quantities of foods consumed per day are based on the USDA's Continuing Survey of Food Intakes by Individuals, 1994−1996 (2 days). The estimated total H-ORAC$_{FL}$ intake was 5558 μmol of TE and for L-ORAC$_{FL}$, 166 μmol of TE per day, respectively. Vegetables, on average, appear to contribute more of the lipophilic components and fruits more of the hydrophilic components. It should be realized that this is an estimated average for all individuals ages 2 and over in the United States. On an individual basis, these numbers will vary considerably from this average depending upon the number of servings of fruits and vegetables consumed daily. If we assume that the average number of servings of fruits and vegetables consumed daily in the United States is 2.5, then an average serving would contain ∼2200 μmol of TE. Thus, if an individual consumed nine servings per day, as is recommended (*69*), total intake could be 20 mmol of TE per day.

Table 11. Estimation of Daily Total Lipophilic and Hydrophilic ORAC$_{FL}$ Intakes from Vegetables, Fruits, and Fruit Juices[a]

food	daily intake[b] (g) (all individuals age 2 and over)	L-ORAC$_{FL}$[c] (μmol of TE/day)	H-ORAC$_{FL}$[d] (μmol of TE/day)
vegetables[e]			
total raw cucumber	3	0.8	3
total lettuce	16	18.4	180
total celery	4	1.6	21
raw broccoli	1	1.7	14
cooked broccoli	5	1.7	61
raw carrot	8	4.7	92
cooked carrot	2	0.3	7
raw tomato	12	2.9	38
cooked tomato	33	11.2	141
raw onion	2	0.2	20
total white potato	13	5.2	135
total dried beans and peas	17	66.6	1536
total cabbage	5	1.0	67
total corn	10	6.4	40
total pepper	4	0.8	29
subtotal		123	2385
fruits and fruit juices			
orange	53	15.4	946
orange juice[f]	42	N/A[h]	454
apple	35	11.2	1127
apple juice[f,g]	17	N/A	79
lemon juice	2	N/A	25
banana	16	10.6	130
grapefruit	6	2.1	91
peach	4	2.0	73
strawberry	3	1.1	106
grape	12	N/A	143
subtotal		42	3174
total		166	5558

[a] For samples with more than one variety, a mean of all varieties was used. [b] Source: USDA's Continuing Survey of Food Intakes by Individuals, 1994–1996, 2 days. [c] Lipophilic ORAC$_{FL}$, expressed as micromoles of Trolox equivalents per day (μmol of TE/day). [d] Hydrophilic ORAC$_{FL}$, expressed as micromoles of Trolox equivalents per day (μmol of TE/day). [e] "Total" means the combination of raw and cooked forms. [f] Data from *J. Agric. Food Chem.* **2003**, *51*, 3273–3279. [g] Mean of two different brands of apple juices. [h] N/A, not available.

Summary. Our studies provide, for the first time, the lipophilic and hydrophilic ORAC$_{FL}$ values for over 100 common foods in U.S. markets using the updated ORAC$_{FL}$ procedure with fluorescein as the fluorescent probe and AAPH as a peroxyl radical generator. Total phenolic concentrations were also measured. Although factors that may affect the antioxidant capacity of foods (i.e., processing, genetics, season, and growing conditions) were discussed, this was not the primary focus of this paper. Our results, when used in conjunction with an appropriate assessment tool for food intake in epidemiology studies, will allow for the estimation of overall intake of antioxidant capacity in relation to health outcomes in the U.S. population.

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LITERATURE CITED

(1) Ames, B. N.; Gold, L. S.; Willet, W. C. The causes and prevention of cancer. *Proc. Natl. Acad. Sci. U.S.A.* **1995**, *92*, 5258−5265.

(2) Diaz, M. N.; Frei, B.; Keaney, J. F., Jr. Antioxidants and atherosclerotic heart disease. *New Engl. J. Med.* **1997**, *337*, 408−416.

(3) Christen, Y. Oxidative stress and Alzheimer's disease. *Am. J. Clin. Nutr.* **2000**, *71*, 621S−629S.

(4) Lang, A. E.; Lozano, A. M. Parkinson's disease. First of two parts. *N. Engl. J. Med.* **1998**, *339*, 111−114.

(5) Ames, B. N.; Shigenaga, M. K.; Hagen, T. M. Oxidants, antioxidants, and the degenerative diseases of aging. *Proc. Natl. Acad. Sci. U.S.A.* **1993**, *90*, 7915−7922.

(6) Young, I. S.; Woodside, J. V. Antioxidants in health and disease. *J. Clin. Pathol.* **2001**, *54*, 176−186.

(7) Davies, K. J. A. Oxidative stress, antioxidant defenses, and damage removal, repair, and replacement systems. *IUBMB Life* **2000**, *50*, 279−289.

(8) Block, G.; Patterson, B.; Suber, A. Fruits, vegetables and cancer pervention: a review of the epidemiological evidence. *Nutr. Cancer* **1992**, *18*, 1−29.

(9) World Cancer Research Fund, American Institute for Cancer Research. *Food, Nutrition and the Prevention of Cancer: A Global Perspective*; American Institute for Cancer Research: Washington, DC, 1997.

(10) Ness, A. R.; Powles, J. W. Fruit and vegetables, and cardiovascular disease: a review. *Int. J. Epidemiol.* **1997**, *26*, 1−13.

(11) Esterbauer, H.; Dieber-Rotheneder, M.; Striegl, G.; Waeg, G. Role of vitamin E in preventing the oxidation of low-density lipoprotein. *Am. J. Clin. Nutr.* **1991**, *53*, 314s−321s.

(12) Jialal, I.; Vega, G. L.; Grundy, S. M. Physiological levels of ascorbate inhibit the oxidative modification of low-density lipoprotein. *Atherosclerosis* **1990**, *82*, 185−191.

(13) Cooper, D. A.; Eldridge A. L.; Peters, J. C. Dietary carotenoids and certain cancer, heart diseases, and age-related macular degeneration: a review of recent research. *Nutr. Rev.* **1999**, *57*, 210−214.

(14) Jha, P.; Flather, M.; Lonn, E.; Farkouh, M.; Yusuf, S. The antioxidant vitamins and cardiovascular disease: a critical review of epidemiological and clinical trial data. *Ann. Intern. Med.* **1995**, *123*, 860−872.

(15) Hercberg, S.; Galan, P.; Preziosi, P. Antioxidant vitamins and cardiovascular disease: Dr. Jekyll or Mr. Hyde? *Am. J. Public Health* **1999**, *89*, 289−291.

(16) Vivekananthan, D. P.; Penn, M. S.; Sapp, S. K.; Hsu, A.; Topol, E. J. Use of antioxidant vitamins for the prevention of cardiovascular disease: meta-analysis of randomised trails. *Lancet* **2003**, *361*, 2017−2023.

(17) Joshipura, K. J.; Ascherio, A.; Manson, J. E.; Stampfer, M. J.; Rimm, E. B.; Speizer, F. E.; Hennekens, C. H.; Spiegelman, D.; Willett, W. Fruit and vegetable intake in relation to risk of ischemic stroke. *JAMA*−*J. Am. Med. Assoc.* **1999**, *282*, 1233−1239.

(18) Eastwood, M. A. Interaction of dietary antioxidants *in vivo*: how fruit and vegetables prevent disease? *Q. J. Med.* **1999**, *92*, 527−530.

(19) Joshipura, K. J.; Hu, F. B.; Manson, J. E.; Stampfer, M. J.; Rimm, E. B.; Speizer, F. E.; Colditz, G.; Ascherio, A.; Rosner, B.; Spiegelman, D.; Willett, W. C. The effect of fruit and vegetable intake on risk for coronary heart disease. *Ann. Intern. Med.* **2001**, *134*, 1106−1114.

(20) Serafini, M.; Bellocco, R.; Wolk, A.; Ekstrom, A. M. Total antioxidant potential of fruit and vegetables and risk of gastric cancer. *Gastroenterology* **2002**, *123*, 85−999.

(21) Cao, G.; Alessio, H. M.; Cutler, R. G. Oxygen-radical absorbance capacity assay for antioxidants. *Free Radical Biol. Med.* **1993**, *14*, 303−311.

(22) Cao, G.; Verdon, C. P.; Wu, A. H. B.; Wang, H.; Prior, R. L. Automated assay of Oxygen Radical Absorbance Capacity with the COBAS FARA II. *Clin. Chem.* **1995**, *41*, 1738−1744.

(23) Delange, R. J.; Glazer, A. N. Phycoerythrin fluorescence-based assay for peroxyl radicals: a screen for biological relevant protective agents. *Anal. Biochem.* **1989**, *177*, 300−306.

(24) Cao, G.; Prior, R. L. Comparison of different analytical methods for assessing total antioxidant capacity of human serum. *Clin. Chem.* **1998**, *44*, 1309−1315.

(25) Prior, R. L.; Cao, G. In vivo total antioxidant capacity: comparison of different analytical methods. *Free Radical Biol. Med.* **1999**, *27*, 1173−1181.

(26) Ou, B.; Hampsch-Woodill, M.; Prior, R. L. Development and validation of an improved Oxygen Radical Absorbance Capacity Assay using fluorescein as the fluorescent probe. *J. Agric. Food Chem.* **2001**, *49*, 4619−4626.

(27) Huang, D.; Ou, B.; Hampsch-Woodill, M.; Flanagan, J. A.; Deemer, E. K. Development and validation of oxygen radical absorbance capacity assay for lipophilic antioxidants using randomly methylated β-cyclodextrin as the solubility enhancer. *J. Agric. Food Chem.* **2002**, *50*, 1815−1821.

(28) Wu, X.; Gu, L.; Holden, J.; Haytowitz, D. B.; Gebhardt, S. E.; Beecher, G.; Prior, R. L. Development of a Database for Total Antioxidant Capacity of foods: a preliminary study. *J. Food Compos. Anal.* **2004**, in press.

(29) Duthie, G.; Crozier, A. Plant-derived phenolic antioxidants. *Curr. Opin. Lipidol.* **2000**, *11*, 43−47.

(30) Pehrsson, P. R.; Haytowitz, D. B.; Holden, J. M.; Perry, C. R.; Beckler, D. G. USDA's National Food and Nutrient Analysis Program: Food Sampling. *J. Food Compos. Anal.* **2000**, *13*, 379−389.

(31) Perry, C. P.; Beckler, D. G.; Pehrsson, P. R.; Holden, J. *A National Sampling Plan for Obtaining Food Products for Nutrient Analysis*, Proceedings of the 2000 Joint Statistical Meetings; American Statistical Association, Section on Survey Research Methods: Indianapolis, IN, 2001; p 267−272.

(32) Prior, R. L.; Hoang, H.; Gu, L.; Wu, X.; Bacchiocca, M.; Howard, L.; Hampsch-Woodill, M.; Huang, D.; Ou, B.; Jacob, R. Assays for hydrophilic and lipophilic antioxidant capacity (oxygen radical absorbance capacity ($ORAC_{FL}$)) of plasma and other biological and food samples. *J. Agric. Food Chem.* **2003**, *51*, 3273−3279.

(33) Singleton, V. L.; Orthofer, R.; Lamuela-Raventos, R. M. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. *Methods in Enzymology 299 (Oxidants and Antioxidants, Part A)*; Academic Press: San Diego, CA, 1999; pp 152−178.

(34) Frankel, E. N.; Meyer, A. S. The problems of using one-dimensional methods to evaluate multifunctional food and biological antioxidants. *J. Sci. Food Agric.* **2000**, *80*, 1925−1941.

(35) Sánchez-Moreno, C. Review: methods used to evaluate the free radical scavenging activity in foods and biological systems. *Food Sci. Technol. Int.* **2002**, *8*, 121−137.

(36) Miller, H. E.; Rigelhof, F.; Marquart, L.; Prakash, A.; Kanter, M. Antioxidant content of whole grain breakfast cereals, fruits and vegetables. *J. Am. Coll. Nutr.* **2000**, *19*, 312S−319S.

(37) Ou, B.; Huang, D.; Hampsch-Woodill, M.; Flanagan, J. A.; Deemer, E. K. Analysis of antioxidant activities of common vegetables employing oxygen radical absorbance capacity (ORAC) and ferric reducing antioxidant power (FRAP) assays: a comparative study. *J. Agric. Food Chem.* **2002**, *50*, 3122−3128.

(38) Halvorsen, B.; Holte, K.; Myhrstad, M. C. W.; Barikmo, I.; Hvattum, E.; Remberg, S. F.; Wold, A., Haffner, K.; Baugerod, H.; Andersen, L. F.; Moskaug, J.; Jacobs, D. R.; Blomhoff, R. A systematic screening of total antioxidants in dietary plants. *J. Nutr.* **2002**, *132*, 461−471.

(39) Pellegrini, N.; Serafini, M.; Colombi, B.; Rio, D. D.; Salvatore, S.; Bianchi, M.; Brighenti, F. Total antioxidant capacity of plant foods, beverages and oils consumed in Italy by three different in vitro assays. *J. Nutr.* **2003**, *133*, 2812−2819.

(40) Cao, G.; Sofic, E.; Prior, R. L. Antioxidant capacity of tea and common vegetables. *J. Agric. Food Chem.* **1996**, *44*, 3426−3431.

(41) Prior, R. L.; Cao, G.; Martin, A.; Sofic, E.; McEwen, J.; O'Brien, C.; Lischner, N.; Ehlenfeldt, M.; Kalt, W.; Krewer, G.; Mainland, C. M. Antioxidant capacity as inflenced by total phenolic and anthocyanin content, maturity, and variety of *Vaccinium* species. *J. Agric. Food Chem.* **1998**, *46*, 2686−2693.

(42) Wang, H.; Cao, G.; Prior, R. L. Total antioxidant capacity of fruits. *J. Agric. Food Chem.* **1996**, *44*, 701−705.

(43) Mazza, G.; Miniati, E. *Anthocyanins in Fruits, Vegetables, and Grains;* CRC Press: Boca Raton, FL, 1993.

(44) Wang, H.; Cao, G.; Prior, R. L. Oxygen radical absorbing capacity of anthocyanins. *J. Agric. Food Chem.* **1997**, *45*, 304−309.

(45) Bergh, B. *Nutritious Value of Avocado*; California Avocado Society: Saticoy, CA, 1992.

(46) Fraser, L. H.; Sabate, J.; Beeson, W. L.; Strahan, T. M. A possible protective effect of nut consumption on risk of coronary disease. The Adventist Health Study. *Arch. Intern. Med.* **1992**, *152*, 1416−1162.

(47) Hu, F. B.; Stampfer, M. J.; Manson, J. E.; Rimm, E. B.; Colditz, G. A.; Rosner, B. A.; Speizer, F. E.; Hennekens, C. H.; Willett, W. C. Frequent nut consumption and risk of coronary heart disease in women: prospective cohort study. *Br. Med. J.* **1998**, *317*, 1341−1345.

(48) Kris-Etherton, P. M.; Zhao, G.; Binkoski, A. E.; Coval, S. M.; Etherton, T. D. The effects of nuts on coronary heart disease risk. *Nutr. Rev.* **2001**, *59*, 103−111.

(49) Fang, N.; Yu, S.; Prior, R. L. LC/MS/MS characterization of phenolic constituents in dried plums. *J. Agric. Food Chem.* **2002**, *50*, 3579−3585.

(50) Kayano, S.; Yamada, N. F.; Suzuki, T.; Ikami, T.; Shioaki, K.; Kikuzaki, H.; Mitani, T.; Nakatani, N. Quantitative evaluation of antioxidant components in prunes (*Prunus domestica* L.). *J. Agric. Food Chem.* **2003**, *51*, 1480−1485.

(51) Arora, D. S.; Kaur, J. Antimicrobial activity of spices. *Int. J. Antimicrob. Agents* **1999**, *12*, 257−262.

(52) Shobana, S.; Naidu, K. A. Antioxidant activity of selected Indian spices. *Prostaglandins Leukotrienes, Essent. Fatty Acids* **2000**, *62*, 107−110.

(53) Dang, M. N.; Takácsová, M.; Nguyen, D. V.; Kristiánová, K. Antioxidant activity of essential oils from various spices. *Nahrung/Food* **2001**, *45*, 64−66.

(54) Lee, K.; Shibamoto, T. Determination of antioxidant potential of volatile extracts isolated from various herbs and spices. *J. Agric. Food Chem.* **2002**, *50*, 4947−4952.

(55) Aggarwal, B. B.; Ahmad, N.; Mukhtar, H. Spices as potent antioxidants with therapeutic potential. *Oxidative Stress Dis.* **2002**, *8* (Handbook of Antioxidants), 437−472.

(56) Matsuura, H.; Chiji, H.; Asakawa, C.; Amano, M.; Yoshihara, T.; Mizutani, J. DPPH radical scavengers from dried leaves of oregano (*Origanum vulgare*). *Biosci., Biotechnol., Biochem.* **2003**, *47*, 2311−2316.

(57) Nagababu, E.; Lakshmaiah, N. Inhibition effect of eugenol on non-enzymatic lipid peroxidation of rat liver mitochondria. *Biochem. Pharmacol.* **1992**, *43*, 2393−2400.

(58) Chang, S. T.; Chen, P. F.; Chang, S. C. Antibacterial activity of leaf essential oils and their constituents from *Cinnamomum osmophloeum*. *J. Ethnopharmacol.* **2001**, *77*, 123−127.

(59) Gu, L.; Kelm, M. A.; Hammerstone, J. F.; Beecher, G.; Holden, J.; Haytowitz, D.; Prior, R. L. Concentration and estimated normal consumption of oligomeric and polymeric flavan-3-ols (proanthocyanidins) in common and infant foods. *J. Nutr.* **2004**, *134*, 613−617.

(60) Adamson, G. E.; Lazarus, S. A.; Mitchell, A. E.; Prior, R. L.; Cao, G.; Jacobs, P. H.; Kremers, B. G.; Hammerstone, J. F.; Rucker, R. B.; Ritter, K. A.; Schmitz, H. H. HPLC method for the quantification of procyanidins in cocoa and chocolate samples and correlation to total antioxidant capacity. *J. Agric. Food Chem.* **1999**, *47*, 4184−4188.

(61) Kaur, C.; Kapoor, H. C. Anti-oxidant activity and total phenolic content of some Asian vegetables. *Int. J. Food Sci. Technol.* **2002**, *37*, 153−161.

(62) Kähkönen, M. P.; Hopia, A. I.; Vuorela, H. J.; Rauha, J.; Pihlaja, K.; Kujala, T. S.; Heinonen, M. Antioxidant activity of plant extracts containing phenolic compounds. *J. Agric. Food. Chem.* **1999**, *47*, 3954−3962.

(63) Pietta, P. Flavonoids as antioxidants. *J. Nat. Prod.* **2000**, *63*, 1035−1042.

(64) Lien, E. J.; Ren, S.; Bui, H.; Wang, R. Quantitative structure−activity relationship analysis of phenolic antioxidants. *Free Radical Biol. Med.* **1999**, *26*, 285−294.

(65) Natella, F.; Nardini, M.; Felice, M. D.; Scaccini, C. Benzoic and cinnamic acid derivatives as antioxidants: structure−activity relation. *J. Agric. Food Chem.* **1999**, *47*, 1453−1459.

(66) Wolfe, K.; Wu, X.; Liu, R. H. Antioxidant activity of apple peels. *J. Agric. Food Chem.* **2003**, *51*, 609−614.

(67) Makris, D. P.; Rossiter, J. T. Domestic processing of onion bulbs (*Allium cepa*) and asparagus spears (*Asparagus officinalis*): effects on flavonol content and antioxidant status. *J. Agric. Food Chem.* **2001**, *49*, 3216−3222.

(68) Takeoka, G. R.; Dao, L.; Flessa, S.; Gillespie, D. M.; Jewell, W. T.; Huebner, B.; Bertow, D.; Ebeler, S. E. Processing effects on lycopene content and antioxidant activity of tomatoes. *J. Agric. Food Chem.* **2001**, *49*, 3713−3717.

(69) Appel, L. J.; Moore, T. J.; Obarzanek, E.; Vollmer, W. M.; Svetkey, L. P.; Sacks, F. M.; Bray, G. A.; Vogt, T. M.; Cutler, J. A.; Windhauser, M. M.; Lin, P. H.; Karanja, N. A clinical trial of the effects of dietary patterns on blood pressure. DASH Collaborative Research Group. *N. Engl. J. Med.* **1997**, *336*, 1117−1124.

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