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ORIGINAL ARTICLE

Individual Sugars, Soluble, and Insoluble Dietary Fiber Contents of 70 High Consumption Foods

Betty W. Li*,[1], Karen W. Andrews†,[2], and Pamela R. Pehrsson†

*Food Composition Laboratory, Beltsville Human Nutrition Research Center, ARS, USDA, U.S.A.; and †Nutrient Data Laboratory, Beltsville Human Nutrition Research Center, ARS, USDA, U.S.A.

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As part of the continuous efforts of the Nutrient Data Laboratory, Agricultural Research Service (ARS), USDA in updating and expanding the carbohydrate data in its database, foods were selected based on dietary fiber content and frequency of consumption. They were analyzed by a commercial testing laboratory under a USDA contract. Individual sugars, soluble and insoluble dietary fiber values of 70 foods in six food groups were reported. Foods included 14 baked products, 10 cereal grains and pastas, 19 fruits, seven legumes, 10 cooked vegetables, and 10 raw vegetables. Except for cereal grains/pasta and legumes, most other foods contained fructose and glucose; sucrose was found in almost all except baked products, which were the most predominant source of maltose. Fruits contained the most total sugar and cereal, grains/pasta the least. Legumes contained the highest amount of total dietary fiber. All these commonly consumed foods, with the exception of cooked white rice, contained both soluble and insoluble dietary fiber. The percent of soluble and insoluble fiber varied across food groups, even within each group. Comparison of data from the commercial laboratory with those of the same food analyzed in the Food Composition Laboratory using different methods indicated there was good agreement between high-performance liquid chromatographic and gas chromatographic methods for the determination of individual sugars. Total dietary fiber as calculated from the sum of soluble and insoluble fiber according to AOAC Method 991.43 and total dietary fiber from direct analysis using a single enzyme-gravimetric method showed high variability ($r^2 < 0.8$) for three of the six food groups, but good agreement for others.

Key Words: Dietary fiber; Individual sugars; U.S. diet.

INTRODUCTION

The U.S. Department of Agriculture (USDA) publishes representative nutrient data for foods in their Standard Reference Data Base, available on the internet and on

[1]To whom correspondence and reprint requests should be addressed. Tel.: +1-301-504-8466. Fax: +1-301-504-8314. E-mail: li@bhnrc.usda.gov
[2]Formerly of Nutrient Data Laboratory.

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CD-ROM (USDA, 2001). Currently, carbohydrate is determined by difference and reported for all foods. Total dietary fiber (TDF) data are provided for most foods. The Nutrient Data Laboratory, ARS, USDA has been updating and expanding the carbohydrate data in Standard Reference since TDF values were first published by Human Nutrition Information Service (Matthews and Pehrsson, 1988). Data have generally been determined using AOAC-approved methods of analysis. Individual and total sugar values were first published in the Home Economics Research Report Number 48 (Matthews *et al.*, 1987). Since then, more values from USDA-sponsored contracts have been added to the database. In response to many inquiries and requests for soluble and insoluble dietary fiber values (obtained as separate fractions in analytical procedures) in the early 1990s, a study was conducted to analyze a large number of foods for these specific food components and individual sugars.

Selection of foods was based on consumption information from the 1989–1991 USDA Continuing Survey of Food Intakes by Individuals (CSFII) (USDA, 1994). The amount (g) of each food consumed as reported in the survey was multiplied by the total dietary fiber content (g/100 g of food). Foods were then ranked in descending order to produce a listing of major contributors of fiber to the American diet. The top 100 foods on this list represented 74% of the TDF consumed in this country. According to the latest CSFII (USDA, 1998), all these foods are still major contributors, with the exception of those listed under legumes and fruits, at least half of which remained on the list. Approximately 70 foods from this list, chosen because they contain both sugars and TDF were procured, prepared and analyzed by a commercial laboratory according to a detailed work plan written into a USDA contract. Foods included 14 baked products, 10 cereal grains and pastas, 19 fruits, seven legumes, 10 cooked vegetables, and 10 raw vegetables. Freeze-dried subsamples of the same foods were stored at -20°C, and analyzed later in the Food Composition Laboratory at the Beltsville Human Nutrition Research Center for verification and comparison of analytical methods.

MATERIALS AND METHODS

All foods were analyzed as eaten. Most vegetables were analyzed either raw or cooked, based on their most commonly eaten form; broccoli and carrots were analyzed both raw and cooked.

Sampling

A simple sampling plan was determined for each food based on Nielsen data from market share information (Nielsen, 1988). Foods were purchased in the Wilson, North Carolina area. For most of the foods (especially the legumes, baked products and cereal grains/pasta), the two top national brands were purchased. In cases where one brand dominated (i.e., Quaker Oats), then only that brand was used, but it was acquired from two major grocery chains. When market data indicated that store brands represented a major market share (i.e., hamburger/hotdog rolls), a major store brand was purchased and composited with the top national brand. For the beverages, the top two national brands were obtained. The fresh fruits and vegetables were purchased from two major grocery chains; the same varieties were purchased when possible. Food ingredient items were acquired from two industrial suppliers.

Sample Preparation

Non-edible parts of fruits and vegetables, such as stem, core, seeds, and skin were removed before further sample preparation. No salt, oil or butter/margarine was added to any food during cooking. Vegetables were cooked until fork tender. All vegetables were cooked in a microwave oven with the exception of corn on the cob, which was boiled, and potatoes which were either baked or boiled. Cereals and pasta were cooked according to package instructions, except no salt or fat was added.

Following preparation, the foods were composited. Equal weight portions of the same food from two different stores or two different brands were composited and blended to a homogenous mixture. Following the removal of a portion from each sample for moisture determination, by drying in a 60°C vacuum oven for $3\frac{1}{2}$-h, the remainder of the mixture was freeze-dried, ground to 30 mesh, and stored at −20°C.

Extraction

Freeze-dried, frozen samples were further dried in a 60°C vacuum oven for $3\frac{1}{2}$-h just before analysis. Samples containing $>10\%$ fat were extracted with hexane to remove most of the fat.

Sugar Determination

Samples were analyzed for mono- and disaccharides by high-performance liquid chromatography (HPLC) according to AOAC Method 982.14 (AOAC, 1997). Sugars were extracted into 50% ethanol; the extract was passed through C_{18} Sep-Pak cartridge and then filtered through a 0.45 μm nylon disc. Separation and quantitation were carried out on an amino-bonded column with a mobile phase of CH_3CN and H_2O (80/20 v:v) and detection with a differential refractometer.

Soluble and Insoluble Dietary Fiber Determination

Samples were analyzed for soluble and insoluble dietary fiber fractions according to AOAC Method 991.43, an enzymatic-gravimetric procedure (Lee *et al.*, 1992). Samples containing a high level of sugar were extracted with 85% ethanol to remove most of the sugars. Residues were suspended in MES-TRIS buffer and digested sequentially with heat-stable α-amylase at 95–100°C, protease at 60°C, and amyloglucosidase at 60°C. Enzyme digestates were filtered through tared fritted glass crucibles. Crucibles containing insoluble dietary fiber were rinsed with dilute alcohol followed by acetone, and dried overnight in a 105°C oven. Filtrates plus washing were mixed with 4 × volume of 95% ethanol to precipitate materials that were soluble in the digestates. After 1 h, precipitates were filtered through tared fritted glass crucibles. One of each set of duplicate insoluble fiber residues and soluble fiber residues was ashed in a muffle furnace at 525°C for 5 h. Another set of residues was used to determine protein as Kjeldahl nitrogen × 6.25. Soluble or insoluble dietary fiber residues (% original sample weight) minus % ash and % crude protein found in the residues were taken to be the values for the respective dietary fiber fraction. Total dietary fiber was calculated as the sum of soluble and insoluble dietary fiber.

Statistical Analysis

All final data and correlation coefficients were calculated using Excel 97 on a PC.

RESULTS AND DISCUSSION

All data shown in Table 1 were obtained through a USDA contract with a commercial laboratory, and are arranged according to food groups and expressed as g/100 g (as eaten).

Sugar Content

Of the 14 baked products, most contained varying levels of fructose, glucose, and maltose; only three contained sucrose. Total sugar content varied between 0.71 for wheat tortilla and 10.08 for whole wheat bread (firm). Of the 10 cereal grains and pasta, eight contained a small amount of sucrose and only four contained fructose, glucose, and/or maltose; total sugar content varied between none detected for cornstarch and 0.78 for cooked instant oatmeal. All of the 19 fruits (except both varieties of avocado) contained fructose, glucose, and sucrose; six contained maltose. Total sugar content varied between 0.16 for avocado (California Haas variety) to 59.15 for seedless raisins. All seven legumes contained sucrose; only two contained fructose and glucose. None of the legumes contained maltose and total sugar content varied between 0.39 for dry, cooked, drained lentils and 4.92 for canned beans with pork and tomato sauce. All of the 10 cooked vegetables contained sucrose, eight contained fructose, seven contained glucose and one contained maltose; total sugar content varied between 0.44 for French fries and 7.37 for microwaved carrots. Of the 10 raw vegetables, all contained fructose; all except broccoli contained glucose, six contained sucrose, and two contained maltose. Total sugar content for raw vegetables varied between 0.53 for spinach and 5.35 for onion. Both raw and cooked forms of broccoli and carrots were analyzed. Total sugar content was higher in the cooked forms; cooking may have released slightly more sugars from the softened plant tissue.

Dietary Fiber Content

The foods selected for this study were considered common dietary fiber sources, all of which contained soluble (except white rice) and insoluble fractions in varying proportions. For baked products, the soluble dietary fiber (SDF) ranged from 0.56 to 1.62, and insoluble dietary fiber (IDF) ranged from 0.85 to 8.64; TDF varied between 1.54 for soft white bread and 9.67 for reduced calorie white bread (firm). Among the cereal grains and pasta, SDF ranged from none detected to 1.54, and IDF ranged from 0.08 to 3.32; TDF content varied between 0.34 for cooked white rice and 3.94 for yellow corn meal. For fruits, SDF ranged from 0.04 to 4.50, and IDF ranged from 0.03 to 11.81; TDF content varied between 0.40 for orange juice and 12.72 for guava. Legumes contained the highest amount of dietary fiber (mostly as IDF); SDF ranging from 0.09 to 1.38, and IDF ranging from 4.02 to 10.56. TDF content varying between 4.53 for canned cowpeas and 10.65 for cooked split peas. For cooked vegetables, SDF ranged from 0.13 to 1.85 and IDF ranged from 1.06 to 4.21; TDF content varied between 2.05 for boiled white potato and 5.23 for cooked lima beans. Vegetables, which are eaten raw, have a lower TDF content when compared to their cooked counterpart or cooked vegetables in general. The SDF for raw vegetables ranged from 0.10 to 0.77 and IDF ranged from 0.88 to 3.06; TDF varied between 0.98 for iceberg lettuce and 3.50 for broccoli.

Marlett (1992) had published the content and composition of dietary fiber in 117 frequently consumed foods, which were analyzed by a modified enzymatic-chemical method. In general, their values were lower than those for similar foods analyzed in

TABLE 1

Sugars and dietary fiber (soluble and insoluble) contents of 70 high consumption foods (g/100 g as eaten)

Foods	Moisture	Fructose	Glucose	Sucrose	Maltose	Total sugar	Sol. fiber	Insol. fiber	TDF
Baked products									
Bagel, plain, frozen	32.33[1]	1.38	0.82	—	3.08	5.28	1.17	1.29	2.46
Bread, white, reduced calorie, soft	41.78	1.13	0.41	—	—	1.54	1.01	8.46	9.47
Bread, white, reduced calorie, firm	39.84	2.67	1.04	2.18	—	5.89	1.03	8.64	9.67
Bread, rye, w/caraway seed	32.28	0.34	—	—	1.71	2.05	1.09	1.98	3.07
Bread, rye, seedless	35.92	—	—	—	3.11	3.26[2]	1.62	2.84	4.46
Bread, wheat, soft	29.50	1.00	0.63	—	—	1.63	1.26	2.13	3.38
Bread, wheat, firm	35.80	0.50	—	—	1.41	1.91	1.56	4.63	6.19
Bread, white, soft	35.51	0.73	0.37	—	0.25	1.35	1.02	0.53	1.54
Bread, white, firm	34.26	2.36	1.88	—	1.29	5.53	1.30	1.36	2.66
Bread, whole wheat, soft	35.70	4.41	3.35	—	0.20	7.96	1.26	4.76	6.01
Bread, whole wheat, firm	35.36	3.82	2.88	—	3.38	10.08	1.51	5.21	6.71
Hamburger/hotdog rolls	32.57	1.94	1.09	—	—	3.03	0.56	1.44	1.99
Tortilla, corn, RTE[3]	37.94	0.03	0.07	0.28	1.53	1.91	1.11	4.39	5.50
Tortilla, flour (wheat), RTE[3]	21.96	—	—	0.71	—	0.71	1.51	0.85	2.37
Cereal grains and pasta									
Corn meal, yellow, degermed	7.05	—	—	0.64	—	0.64	0.62	3.32	3.94
Cornstarch, wholesale	7.66	—	—	—	—	0	1.00	0.08	1.08
Brown rice, long grain, cooked	68.60	—	—	0.45	—	0.45	0.44	2.89	3.33
Flour, all purpose, bleached	9.63	—	—	0.22	0.09	0.31	1.54	1.50	3.04
Grits, quick, cooked	84.09	—	0.09	0.20	—	0.29	0.12	1.14	1.26
Grits, instant, cooked	73.79	0.08	—	0.20	0.07	0.35	0.07	1.48	1.55
Oatmeal, instant, cooked	78.71	—	—	0.78	—	0.78	1.45	1.14	2.58
Oatmeal, regular, cooked	85.51	—	—	0.13	—	0.13	0.42	1.23	1.65
Spaghetti, cooked	54.33	—	—	—	0.47	0.47	0.54	1.33	2.06
White rice, long grain, cooked	68.10	—	—	0.03	—	0.03	—	0.34	0.34
Fruits									
Apple (Red delicious), raw, ripe w/skin	83.60	5.60	1.83	2.66	—	10.09	0.67	1.54	2.21
Avocado (Calfornia, Haas), raw, ripe	64.59	0.10	0.06	—	—	0.16	2.03	3.51	5.53

(*continued on next page*)

TABLE 1 (*continued*)

Foods	Moisture	Fructose	Glucose	Sucrose	Maltose	Total sugar	Sol. fiber	Insol. fiber	TDF
Fruits									
Avocado (Florida, Fuerte), raw, ripe	79.22	0.25	2.17	—	—	2.42	1.25	5.48	6.72
Bananas, raw, ripe	73.37	2.98	2.43	5.97	—	11.38	0.58	1.21	1.79
Grapefruit, raw, white, ripe	90.00	1.66	1.59	2.37	0.11	5.73	0.58	0.32	0.89
Grapes (Thompson seedless), raw, ripe	81.76	6.78	6.07	0.07	0.06	12.98	0.24	0.36	0.60
Guava, raw, ripe	79.51	1.80	0.76	1.11	—	3.67	1.54	11.81	12.72
Mango, raw, ripe	83.71	3.80	0.66	8.27	—	12.73	0.69	1.08	1.76
Nectarine, raw, ripe, w/skin	85.30	3.69	3.32	1.11	0.09	8.21	0.98	1.06	2.04
Oranges (Navel), raw, ripe	84.58	2.03	1.88	4.46	—	8.37	1.37	0.99	2.35
Orange juice, retail, from concentrate	82.90	2.02	2.03	4.10	—	8.15	0.28	0.03	0.31
Peaches, raw, ripe, w/skin	83.10	4.01	4.52	0.21	—	8.74	1.31	1.54	2.85
Peaches, raw, ripe, w/o skin	83.49	3.92	3.52	3.88	—	11.32	0.84	1.16	2.00
Pears, raw, ripe, w/skin	83.24	5.30	4.20	1.21	—	10.71	0.92	2.25	3.16
Pineapple (smooth Cayenne), raw, ripe	85.43	2.83	2.58	3.83	—	9.24	0.04	1.42	1.46
Plum, raw, ripe, w/skin	85.57	3.28	5.10	0.10	0.17	8.65	1.12	1.76	2.87
Prunes, pitted	24.68	12.35	25.42	0.15	—	37.92	4.50	3.63	8.13
Raisins, seedless	6.61	29.89	28.10	0.98	0.18	59.15	0.90	2.17	3.07
Watermelon, raw, ripe	91.11	2.72	0.67	2.87	0.03	6.29	0.13	0.27	0.40
Legumes									
Beans, canned, w/pork and tomato sauce	72.43	1.27	0.87	2.78	—	4.92	1.38	4.02	5.40
Chick peas, canned, drained	66.79	—	—	0.44	—	0.44	0.41	5.79	6.19
Cowpeas, canned, drained	69.95	—	—	0.42	—	0.42	0.43	4.11	4.53
Lentils, dry, cooked, drained	71.46	—	—	0.39	—	0.39	0.44	5.42	5.86
Pinto beans, canned, drained	69.16	—	—	0.54	—	0.54	0.99	5.66	6.65
Red kidney beans, can, drained	65.53	0.10	0.23	3.47	—	3.8	1.36	5.77	7.13
Split peas, dry, cooked, drained	62.71	—	—	0.65	—	0.65	0.09	10.56	10.65
Vegetables, cooked									
Beans, green, fresh, microwaved	86.73	1.25	0.25	0.91	—	2.41	1.38	2.93	4.31
Broccoli, fresh, microwaved	87.03	0.89	0.73	0.30	—	1.92	1.85	2.81	4.66

Carrots, fresh, microwaved	86.07	0.49	0.47	6.41	—	7.37	1.58	2.29	3.87
Corn, yellow, from cob, grocery store	78.98	1.56	0.64	0.73	—	2.93	0.13	4.12	4.25
Corn, yellow, from cob, farm market	74.50	1.55	1.39	3.66	—	6.6	0.25	2.63	2.87
Lima beans, immature, froz., microwaved	73.95	0.21	—	0.56	—	0.77	1.02	4.21	5.23
Peas, green, froz., microwaved	76.59	—	—	6.09	—	6.09	0.94	2.61	3.54
Potato, french fries, fast food	33.84	—	—	0.44	—	0.44	0.67	3.44	4.11
Potato, white, baked, w/skin	72.41	0.17	0.15	0.19	—	0.51	0.61	1.70	2.31
Potato, white, boiled, w/o skin	66.99	0.11	0.16	0.18	0.06	0.51	0.99	1.06	2.05
Vegetables, raw									
Broccoli, raw	89.10	0.28	—	—	0.42	0.7	0.44	3.06	3.50
Cabbage, green, raw	90.84	2.17	1.64	0.11	—	3.92	0.46	1.79	2.24
Carrots, raw	88.03	0.39	0.28	4.19	—	4.86	0.49	2.39	2.88
Cauliflower, raw	90.67	1.35	0.83	0.30	—	2.48	0.47	2.15	2.62
Cucumber, raw, with peel	95.60	0.82	0.67	—	—	1.49	0.20	0.94	1.14
Lettuce, iceberg, raw	95.48	0.91	0.67	0.02	0.02	1.62	0.10	0.88	0.98
Onion, mature, raw	85.57	1.76	2.21	1.38	—	5.35	0.71	1.22	1.93
Pepper, sweet, green, raw	94.43	1.04	0.71	0.18	—	1.93	0.53	0.99	1.52
Tomatoes, red, ripe, raw	94.42	1.19	0.49	—	—	1.68	0.15	1.19	1.34
Spinach, raw	90.28	0.51	0.02	—	—	0.53	0.77	2.43	3.20

[1]Mean of duplicate analyses.
[2]Contained galactose (0.15 g/100 g).
[3]RTE=ready-to-eat.

TABLE 2

Squared correlation coefficient (r^2) between total sugar and total dietary fiber values from different methods

Food	Total sugar[1]	Total dietary fiber[2]
Baked products	0.89	0.95
Cereal grains and pasta	0.90	0.64
Fruits	0.98	0.97
Legumes	0.97	0.78
Vegetables, cooked	0.93	0.76
Vegetables, raw	0.97	0.91

[1]HPLC versus GC.
[2]AOAC method 991.43 versus single enzyme method.

this study by an enzymatic-gravimetric method. Vollendorf and Marlett (1993) and Mongeau and Brassard (1989) conducted studies comparing two or three dietary fiber methods for the analysis of a variety of foods. They concluded that enzymatic-gravimetric methods (e.g., AOAC method 991.43) generate higher fiber values than enzymatic-chemical methods (e.g., AOAC method 994.13). For this study, we chose AOAC Method 991.43 because it is a method that was adopted for nutrition labeling of dietary fiber by the U.S. Food and Drug Administration (USDHHS, 1993).

Portions of the freeze-dried samples of the 70 foods were also analyzed in the Food Composition Laboratory, ARS, USDA for individual sugars and total dietary fiber content (Li, 1996). Individual sugars were determined using the same extraction procedures described above; and a gas chromatographic (GC) technique for separation and quantitation. Total dietary fiber was determined by the single enzyme-gravimetric method. Comparisons were made between HPLC and GC for total sugars and between the sum of soluble and insoluble dietary fiber fractions and TDF by direct measurement. Lee *et al.* (1992) showed that calculated TDF values were comparable to those from direct analysis using the method described in their collaborative study. Table 2 gives the squared correlation coefficient for different methods by each food group. Good agreement was found among total sugar values obtained in two analytical laboratories using different methods (r^2 ranged from 0.89 for baked products to 0.98 for fruits). Greater variations were found for TDF values (r^2 varied between 0.64 for cereal grains/pasta and 0.97 for fruits).

CONCLUSIONS

Individual sugar profiles were characterized for selected foods. Most baked products contained fructose, glucose, maltose and no sucrose; cereal grains and pasta contained mainly sucrose, though in low levels compared to all other food groups. Almost all fruits contained fructose, glucose, and sucrose. Legumes contained mostly sucrose and no detectable maltose; vegetables that are eaten cooked contained more sucrose than those eaten raw. Overall, fruits contain the most total sugar and cereal grains/pasta the least.

Of the 70 foods tested, only six had TDF less than 1 g/100 g (as eaten). Therefore, the remaining 64 foods may be considered good sources of dietary fiber. The proportion of SDF to IDF varied across the food groups and even within each food group. The results of this study support evaluating foods on a case-by-case basis rather than developing generalizations on the relative proportions of fiber fractions according to food groups.

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