

Daily boron intake from the American diet

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ABSTRACT

Interest in boron as a naturally occurring trace element nutrient from the food supply is increasing. Mounting evidence suggests that boron is essential to human beings. This study explores the major food and beverage contributors of boron and estimates of daily boron intake from the American diet. Previous estimates in the literature of dietary boron consumption are based on limited foods and population segments. In this study we provide a more comprehensive assessment of boron consumption by the US population. A boron nutrient database of 1,944 individual foods was developed. These foods represent 95.3% by weight of all foods consumed in the US Department of Agriculture 1989-1991 Continuing Survey of Food Intakes by Individuals (1989-1991 CSFII). The Boron Nutrient Database (version 1.0) was then linked to the 3-day food records of 11,009 respondents to the 1989-1991 CSFII to generate the average daily boron intake for each person. The weighted 5th percentile, median, mean, and 95th percentile boron intakes, respectively, are 0.43, 1.02, 1.17 and 2.42 mg/day for men; 0.33, 0.83, 0.96 and 1.94 mg/day for women; and 0.40, 0.86, 1.01 and 2.18 mg/day for pregnant women. For vegetarian adults, these intakes are 0.46, 1.30, 1.47 and 2.74 mg/day for men and 0.33, 1.00, 1.29 and 4.18 mg/day for women. The top 2 boron contributors, coffee and milk, are low in boron, yet they make up 12% of the total boron intake by virtue of the volume consumed. Among the top 50 boron contributors, peanut butter, wine, raisins, peanuts, and other nuts are high in boron. As more data become available on daily boron requirements, the results of this study may be used to assess whether Americans' daily intake of boron is adequate. *J Am Diet Assoc.* 1999; 99:335-340.

Two expert scientific committees have concluded that boron is a probable essential element: A World Health Organization Expert Committee on Trace Elements in Human Nutrition declared that boron is "probably essential" (1), and participants at a workshop on recommended intakes for trace mineral elements sponsored by the US Department of Agriculture (USDA) concluded that a provisional Recommended Dietary Allowance should be established for boron (2). The 10th edition of the *Recommended Dietary Allowances* stated that there is substantial evidence to establish the essentiality of some trace elements, including boron, in animals (3). However, more information about actual boron intakes in the US population is needed before recommended intake levels can be determined (2).

Boron is a trace mineral element that occurs naturally in the food supply and is a ubiquitous component of the American diet. It does not exist as elemental boron in foods or beverages but as 1 or more inorganic, oxygen-containing borates. Studies indicate that there are organic forms of boron (borate esters) in foods, such as the boron present in a polysaccharide fraction in wine (4). Boron has long been known to be an essential micronutrient for the growth of most plants, and there is considerable evidence that it is essential for animals and human beings (1-10).

Since 1981, many experiments with animals have demonstrated that boron deprivation affects the composition or function of several bodily components, including the skeleton and brain, and that it affects biochemical indexes associated with the metabolism of several other nutrients, including calcium, copper, nitrogen, and cholecalciferol (2,6,7). The responses to low intake of dietary boron in most of these experiments were enhanced when the animal was simultaneously exposed to nutritional stress, such as a deficiency in vitamin D, calcium, cholecalciferol, magnesium, or potassium (6,7). Boron appears to positively affect calcium and magnesium metabolism and may be needed for energy substrate use and membrane function (6,7). Boron deficiency has been reported in studies of rats and chickens (7) and has been suggested in 3 clinical studies of human beings (6,8). Recent evidence suggests that boron is essential for early life development in *Xenopus* frogs and zebra fish (9,10).

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Table 1Dietary boron intake (mg/day) based on data from 1989-91 CSFII^a and the Boron Nutrient Database^b

Group/age	n	Mean±SD ^c	Percentiles					High
			5th	10th	50th	90th	95th	
School-age males and females								
4-8 y	993	0.85±0.40	0.35	0.40	0.79	1.39	1.60	3.32
9-13 y	943	0.91±0.45	0.32	0.40	0.85	1.50	1.82	2.69
14-18 y	759	0.88±0.47	0.35	0.40	0.79	1.45	1.95	3.83
Males ≥19y								
19-30 y	3,433	1.17±0.65	0.43	0.54	1.02	1.97	2.42	9.64
31-50 y	878	1.07±0.64	0.40	0.48	0.92	1.88	2.08	9.64
51-70 y	1,297	1.17±0.64	0.43	0.54	1.01	2.04	2.52	4.52
>70 y	884	1.28±0.67	0.49	0.59	1.14	2.04	2.53	7.04
Vegetarian	374	1.19±0.61	0.47	0.58	1.06	1.88	2.18	5.09
	49	1.47±0.70	0.46	0.53	1.30	2.60	2.74	3.60
Females ≥19y								
19-30 y	4,881	0.96±0.55	0.33	0.42	0.83	1.58	1.94	8.50
31-50 y	1,199	0.86±0.55	0.30	0.35	0.72	1.48	1.82	8.50
51-70 y	1,734	0.96±0.55	0.34	0.42	0.83	1.58	1.97	5.44
>70 y	1,220	1.05±0.55	0.39	0.50	0.94	1.69	2.05	7.13
Vegetarian	728	0.97±0.52	0.37	0.44	0.87	1.55	1.80	5.73
	130	1.29±1.12	0.33	0.35	1.00	2.38	4.18	5.75
Pregnant women	130	1.01±0.72	0.40	0.45	0.86	1.54	2.18	8.50

^aUS Department of Agriculture 1989-91 Continuing Survey of Food Intakes by Individuals (weighted, 3-day averages) (17-19).^bBoron Nutrient Database (version 1.0) developed by the authors for this research.^cSD=standard deviation.

Data on dietary boron intake by human beings are fairly sparse. Boron is not included in the USDA nutrient databases (11,12), and no comprehensive analytical database exists on the boron content of specific foods. Previous estimates of average boron intake, summarized as ranging from 1 to 2 mg/day for adults (8), are based on a limited number of foods and population segments. The more complete studies yielded the following results for boron intake: 2 US Food and Drug Administration Total Diet Studies reported mean intakes of 1.52±0.38 mg/day (13,14) and 1.21±0.07 mg/day (standard deviation of analytical method) for men (15); and 1-day diet composites collected from 22 premenopausal Canadian women contained 1.33±0.13 mg (standard error of the mean) (16).

One important aspect of our study is that we determined average boron intake per individual. This allowed frequency distributions and other descriptive statistics to be generated for various populations (age and gender groups, pregnant women, vegetarians). By using the USDA 1989-1991 Continuing Survey of Food Intakes by Individuals (1989-1991 CSFII) (17-19) and all credible analytical data from the published literature on boron in foods and food ingredients, we developed a boron nutrient database and linked it with the food consumption records collected over a 3-year period for 11,009 people.

The 3 primary objectives of this research were to create a boron nutrient database, to determine daily intakes of dietary boron of individuals, and to determine major sources of boron in the diet. These estimates of dietary boron intake provide the customary consumption data that are necessary for eventual determination of recommended levels of daily intake.

CREATING A BORON NUTRIENT DATABASE

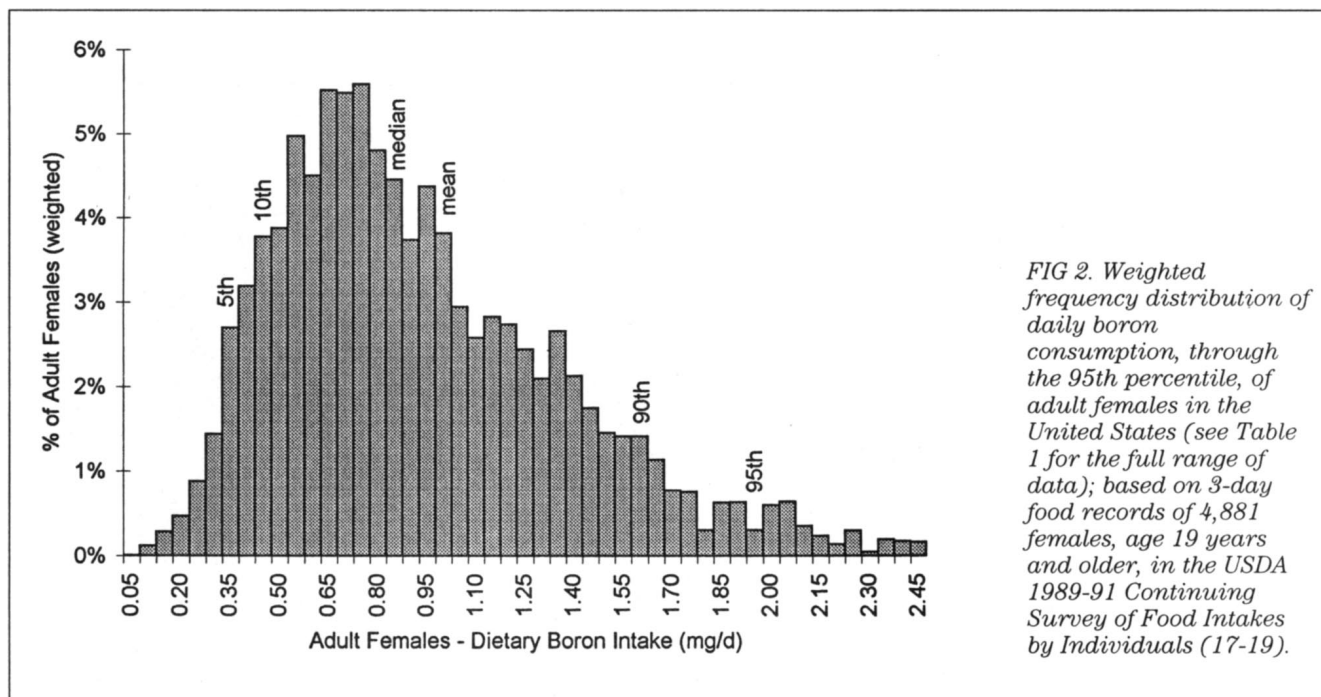
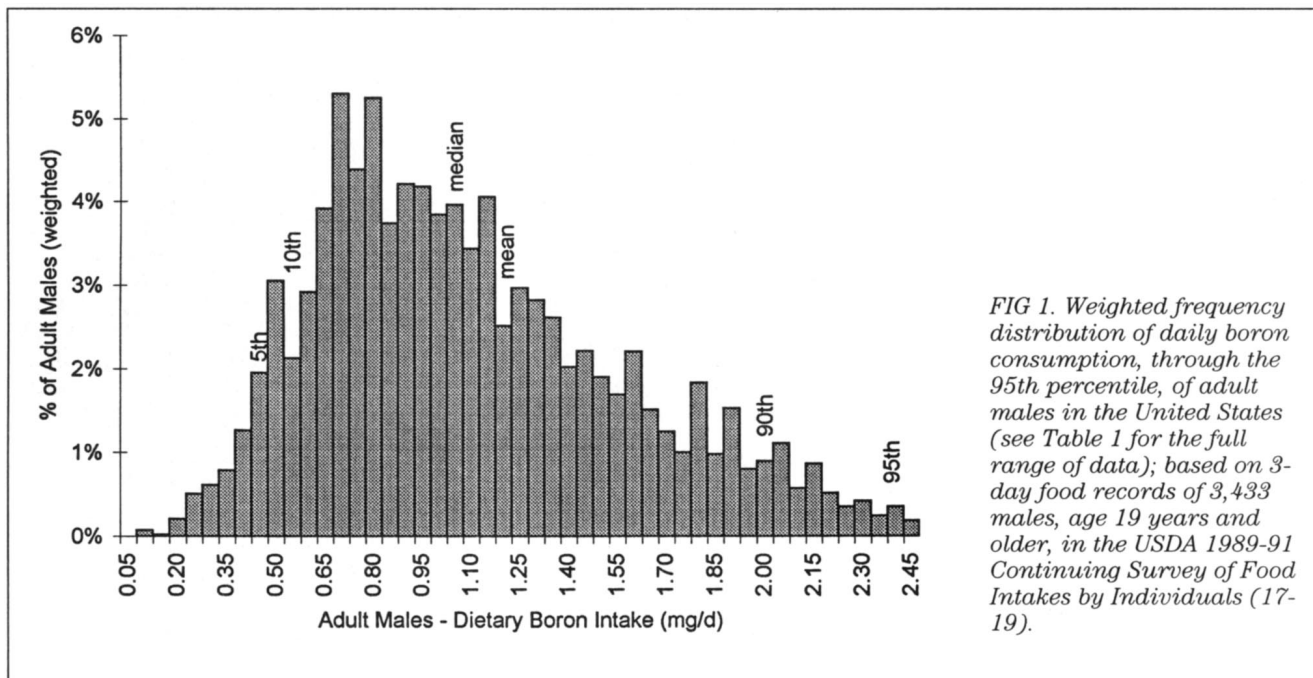
Because the USDA nutrient databases do not contain data for boron in foods, a multiphase process was established to determine daily boron intakes. The process involved searching the literature for analytical boron concentrations in foods, applying those data to other foods by calculation, and linking the refined boron database to results of the 1989-1991 CSFII. These methods are similar to those established by USDA and others for establishing databases for other nutrients (20-23).

Analytical Values from Literature

A comprehensive literature search was conducted to obtain the boron concentrations of individual foods. This involved conducting an online computer search, contacting scientists at the US Food and Drug Administration and USDA, and obtaining many references from the library files at US Borax (Valencia, Calif). Data of approximately 70 published, literature references were reviewed for possible use in the boron nutrient database. About half of the references contained analytical data, research documentation, and/or analytical methods for the determination of boron in specific foods. Those containing duplicate data or estimated ranges that could not be verified to be from original, published analyses were eliminated. Only references believed to contain original boron data for foods were selected for further review.

The first step in evaluating the analytical data was to assemble the information in such a way that comparisons could be made among data from varying sources. A preliminary database was created that included information about each data source (such as analytical methods, sample preparation, number of food items, country of origin, and age of data). Conversion factors were determined for the various concentration units reported in the literature so that all boron concentrations would be expressed as µg/100 g. Data reported on a dry-weight basis were converted to wet weight using actual moisture levels or typical levels from USDA nutrient data. Data reported as boric acid were converted to boron (H₃BO₃ is 17.5% boron by weight). Because boron is an essential nutrient for plants and is known to be in all foods, data reported as below detection limits were assigned a value that was half the stated detection limit for the analytical method (eg, <2 µg boron per 100 g was assigned a value of 1 µg boron per 100 g). The final boron consumption estimates are approximately 0.3% higher as a result of using half the detection limit rather than zero for these data. This preliminary boron database consisted of 1,063 analytical values from 22 references.

The preliminary database was then evaluated to determine whether the data points were analytically robust and to further identify duplicate or unpublished data. Six references were



eliminated for the following reasons: 1 reference was determined to be an internal, unpublished review document from US Borax files; 4 references were eliminated because they were published between 1936 and 1968 and were found to be based on older, less sensitive analytical methods, thus calling into question the accuracy of the boron determinations; and 1 study was eliminated because it was an analysis of foreign fruit drinks of unknown composition.

The evaluation resulted in a database of 885 analytical boron concentrations derived from 16 literature references. This includes boron concentrations of 234 foods analyzed in the US Total Diet Study (15) as well as 204 boron concentra-

tions from various other US sources (24-27), for a total of 438 US data points. Because analytical data on the boron content of US foods are scant, we included data from sources outside the United States: 338 boron concentrations were of Finnish foods (28-33) and the remaining 109 boron concentrations were of foods from various sources in the United Kingdom (34), Italy (35,36), Japan (37), and China (38). The Finnish data, as well as those from the United Kingdom, Italy, Japan, and China, may not be directly comparable to the data for foods in the United States. Multiple data points for single foods were then averaged to create the final analytical boron database of 527 foods.

Calculated Values

A total of 4,980 foods were reported as consumed in the 1989-1991 CSFII. To help prioritize the assignment of boron concentrations to the survey foods, a report of the frequency and amount consumed for each food was generated from the 1989-1991 CSFII data (12,17-19) and the analytical boron database. The report listed each survey food, USDA food code, frequency of consumption, total grams consumed, proximate values, and boron concentration, if known. Foods in the top 97% of consumed weight were flagged and separated into 9 major food groups according to their USDA survey food codes (1=milk and milk products; 2=meat, poultry, fish, and mixtures; 3=eggs; 4=dry beans, peas, other legumes, nuts, and seeds; 5=grain products; 6=fruits; 7=vegetables; 8=fats, oils, and salad dressings; and 9=sugars, sweets, and beverages). Evaluation of similar foods was thus simplified, as the first 3 digits of these codes represent major and minor food groupings.

Additional boron concentrations for 1,417 foods were then calculated on the basis of the data from the 527 source foods; emphasis was placed on highly consumed foods and foods with high boron content. One hundred fifty-one of the 1,417 foods were equivalent to the source foods and were assigned the same boron concentrations.

Boron calculations for 691 foods were based on a comparison of the solids, carbohydrate, and/or protein content of a source food with that of a target food, because they were minor variations of each other (eg, raw vs cooked, sweetened vs unsweetened, dry vs diluted). For example, the boron in baked potato was calculated from raw potato data using the solids ratio to account for moisture loss. Carbohydrate comparisons were made to calculate the amount of added sugar in foods, such as sweetened strawberries vs unsweetened strawberries. Carbohydrate ratios were used to account for moisture and/or fat differences in foods, such as breads (eg, French bread vs white bread). In a similar manner, protein ratios were used to account for moisture and/or fat differences in meats, such as roast, lean only vs roast, lean and fat.

Boron concentrations for 488 foods were recipe calculations derived from the 1989-1991 CSFII nutrient database and technical support files (12) and the actual or estimated boron concentration of each ingredient. Recipes included complex mixed dishes and simpler combinations, such as chicken and flour for breaded chicken, and raisins and bread for raisin bread.

Calculations for 87 foods involved substitutions of similar foods in combination with adjustments for moisture or other proximate differences. For example, the boron concentrations for several species of fish were derived from data on other species; 8 ready-to-eat breakfast cereals were assigned the average boron value of other ready-to-eat cereals; spinach was used for turnip greens, whiskey for tequila, and so on.

The resulting boron database contained 1,944 foods, which represented 95.3% by weight of all food consumed in the 1989-1991 CSFII. Because we were not able to assign boron values for 4.7% of the total grams of food consumed in the 1989-1991 CSFII, a slight negative bias may have occurred in the final consumption calculations for this study. The bias should be far less than 4.7%, however, because most foods with the highest boron concentrations were included (eg, nuts, legumes, raisins, other fruits, wine).

DAILY INTAKE OF DIETARY BORON

The final Boron Nutrient Database (version 1.0) was linked to the 3-day food records of 11,009 persons (aged 4 years and older) in the 1989-1991 CSFII to calculate the average daily boron intake of each person. Weighted frequency distributions

and other descriptive statistics were then generated for various populations (age and gender groups, pregnant women, and vegetarians). The weighted sample is designed to represent the diet of the US population throughout the year, as detailed in the 1989-1991 CSFII documentation (17-19). The age groupings were selected according to the Food and Nutrition Board life-stage groups for Dietary Reference Intake values (39).

The final validity checks included an examination of the outliers after the boron content of the individual diets had been calculated. The detailed food consumption records for the lowest and highest amounts of boron intake for each age and gender group were reviewed for potential errors. The highest day of boron consumption by 1 individual was found to be in error (24.3 mg/day) and was removed from the data: 600 g prepared ice tea consumed by 1 man was erroneously coded by USDA as dry, instant tea powder. Other unusually high boron intakes were retained, however, because they were within the realm of possibility and could not be confirmed to be in error.

Table 1 summarizes the descriptive statistics of dietary boron intake for each age and gender group, as well as for vegetarian adults and pregnant women. In all cases, medians are lower (generally by 0.1 to 0.2 mg) than the means. The highest median boron intake is 1.30 mg/day for adult male vegetarians. The lowest median intake (0.72 mg/day) was obtained for 19- to 30-year-old women. The medians for adult male and female vegetarians are 27% and 20% higher, respectively, than the medians for all adult males and females.

It is apparent that very large variations in boron intakes occur across the US adult population. Intakes range from almost no boron (0.02 mg/day) to greater than 9 mg/day. Detailed distributions for men and women are illustrated in Figures 1 and 2.

SOURCES OF BORON IN THE DIET

Table 2 lists the 50 major contributors of boron in the diet. Foods consumed in the 1989-1991 CSFII were grouped into 151 food categories according to nutrient and ingredient similarities; the USDA food coding manual (12) and 1989-1991 CSFII documentation (17-19) were used as guides. The percentage of total boron contribution was calculated for each category. Food categories were ranked by their percentage contribution to total dietary boron intake. The top 50 food categories cumulatively contribute 77% of all boron consumed in the 1989-1991 CSFII. A representative food was selected from each food category. Table 2 lists the representative food, its boron content, analytical references, and whether the reported boron content is based on analytical data, analytical data adjusted for minor variation of the food, or a recipe calculation.

Coffee and milk are the top 2 contributors by virtue of the volume with which they are consumed. Several other beverages are among the major contributors, namely, orange juice, wine, apple juice, cola drinks, grape juice, fruit-flavored drinks, tea, tomato juice, and beer. Fruits, vegetables, and nuts are also widely represented, for example, apples, potatoes, peanut butter, peaches, and bananas. Among the top 50 boron contributors, peanut butter, wine, raisins, and peanuts are high in boron.

IMPLICATIONS FOR DIETITIANS

In general, the daily boron intakes that were generated in this study are slightly lower than what we anticipated based on previous estimates of US intake. Our study was more comprehensive in that it was based on a greater number of foods, more days of consumption, and newer dietary information. Another important difference is that our study determined boron intake

Table 2Fifty major contributors of boron in the diet (data from 1989-91 CSFII^a and the Boron Nutrient Database^b)

Rank	Food category ^c	% total boron consumed	Cumulative % of boron	Representative food from category ^d	Boron content ^e (µg/100g)	Analytical reference
1	Coffee	6.7	6.7	Coffee, made from ground coffee beans ^f	29	26,31
2	Milk	5.1	11.8	Milk, whole ^f	18	15,26,33
3	Apples	5.1	16.9	Apples, raw ^f	360	15,26,30,37
4	Beans, dried, cooked	4.8	21.7	Beans, refried ^g	400	15,33
5	Potatoes	4.8	26.5	French fries, from frozen, deep fried ^g	110	15
6	Orange juice	3.3	29.8	Orange juice, not further specified ^f	72	15,26,27,30
7	Peanut butter	3.2	33.0	Peanut butter ^f	1,450	15
8	Wine	2.9	35.9	Wine, table, dry ^f	610	15,31,35-37
9	Apple juice	2.4	38.2	Apple juice ^f	180	15,26,27,30
10	Cola drinks	2.1	40.4	Soft drink, cola-type ^f	13	15
11	Peaches	1.8	42.2	Peaches, raw ^f	530	15,30
12	Bread and rolls, white	1.7	43.9	Bread, white ^f	46	15,26,27
13	Banana	1.6	45.5	Banana, raw ^f	135	15,26,30,37
14	Cereals, ready to eat	1.5	46.9	Bran flakes with raisins ^f	450	15
15	Grapes	1.4	48.4	Grapes, raw, not specified as to type ^f	490	15,26,30
16	Grape juice	1.4	49.7	Grape juice, unsweetened ^f	300	15,26
17	Lettuce, lettuce salad	1.4	51.1	Lettuce, raw ^f	105	15,26,30
18	Broccoli	1.3	52.4	Broccoli, boiled ^f	250	15
19	Oranges	1.2	53.6	Oranges, raw ^f	260	15,26,30,37
20	Pizza	1.2	54.8	Pizza, with meat, thin crust ^h	76	15,25-27,30-34,37
21	Fruit-flavored drinks	1.2	56.0	Fruit-flavored drink, from powdered ^g	16	15
22	Potato chips	1.2	57.1	Potato chips ^f	325	15
23	Chili con carne	1.1	58.2	Chili con carne, with beans ^f	170	15
24	Tea	1.1	59.4	Tea, leaf, brewed ^f	9	15,26,31,36
25	Applesauce	1.1	60.4	Applesauce, unsweetened ^f	280	27
26	Raisins	1.0	61.5	Raisins ^f	2,200	15,30
27	Fruit cocktail	1.0	62.5	Fruit cocktail, canned, in heavy syrup ^f	240	15,30
28	Rice	1.0	63.5	Rice, white, cooked ^f	32	15
29	Beans, string	1.0	64.4	Beans, string, cooked ^f	120	15
30	Tomatoes, tomato juice	0.8	65.3	Tomatoes, raw ^f	63	15,26,30
31	Sandwiches with meat	0.8	66.1	Hamburger, with tomato and/or ketchup ^h	51	15,26,27,30,31,37
32	Peanuts	0.8	66.8	Peanuts, roasted, salted ^f	1,700	26
33	Pears	0.7	67.5	Pears, raw ^f	280	15,30
34	Spaghetti sauce, tomato sauce	0.7	68.2	Spaghetti sauce ^h	120	15,26,27,30,31,34,37
35	Soups, meat based	0.7	68.8	Beef vegetable soup with potato, stew type ^h	140	15,26,30,31,37
36	Spaghetti, tomato-based sauce	0.6	69.5	Spaghetti with meat sauce ^f	65	15
37	Ice cream, milk desserts	0.6	70.1	Ice cream, regular, not chocolate ^f	22	26,27,33
38	Cantaloupe	0.6	70.8	Cantaloupe, raw ^f	180	15,26
39	Coleslaw, cabbage	0.6	71.4	Coleslaw with dressing ^f	120	15
40	Carrots	0.6	72.0	Carrots, raw or frozen ^f	230	15,26,30,37
41	Peas, cowpeas, field peas	0.6	72.7	Peas, black-eyed, cooked, fat added ^g	460	15
42	Chicken	0.6	73.2	Chicken breast, broiled, skin not eaten ^g	27	15
43	Peas, green	0.6	73.8	Peas, green, cooked ^f	130	15
44	Onions	0.6	74.3	Onions, raw ^f	190	15,26,30,37
45	Beans, lima	0.5	74.9	Beans, lima, dry, cooked, fat added ^g	370	15
46	Beef stew	0.5	75.4	Beef and vegetable stew ^f	120	15
47	Fish and shellfish	0.5	75.9	Tuna, canned, water packed ^f	54	26
48	Spinach, collards, turnip greens	0.5	76.4	Spinach, boiled ^f	180	15
49	Corn	0.5	76.9	Corn, yellow, cooked ^f	46	15
50	Beer	0.5	77.4	Beer ^f	12	15,31

^aUS Department of Agriculture 1989-91 Continuing Survey of Food Intakes by Individuals (unweighted, all respondents) (17-19).^bBoron Nutrient Database (version 1.0) developed by the authors for this research.^cFoods were grouped into 151 categories according to ingredient and nutrient similarities.^dIndividual food with the highest percentage contribution of total boron within the category.^eBoron content of representative food from the food category.^fBoron content from analytical data.^gAnalytical boron content adjusted for minor variation of food.^hBoron content calculated from recipe.

for each individual. Previous studies (13-15) were based on average diets and provided estimates of the mean for each age and gender group but not ranges or distributions.

One might have expected a higher median boron intake for vegetarians than that reported in this study. Perhaps the results indicate that although vegetarians consume more boron-rich fruits, nuts, and legumes, they generally also consume more low-boron grain products and less total energy than nonvegetarians (40).

As data become available on daily boron requirements, the results of this study may be used to assess whether Americans are receiving adequate daily boron. To further improve estimates of boron consumption, food and beverage manufacturers are urged to determine the boron concentrations of their products.

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