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Estimated Dietary Flavonoid Intake and Major Food Sources of U.S. Adults[1,2]

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Abstract

Estimating flavonoid intake is a first step toward documenting the protective effects of flavonoids against risk of chronic diseases. Although flavonoids are important dietary sources of antioxidants, insufficient data on the comprehensive food composition of flavonoids have delayed the assessment of dietary intake in a population. We aimed to estimate the dietary flavonoid intake in U.S. adults and its sociodemographic subgroups and to document major dietary sources of flavonoids. We expanded the recently released USDA Flavonoid Database to increase its correspondence with the 24-h dietary recall (DR) of the NHANES 1999–2002. We systematically assigned a particular food code to all foods that were prepared or processed similarly. This expanded database included 87% of fruits and fruit juices, 86% of vegetables, 75% of legumes, and, overall, 45% of all foods reported by the 24-h DR of the NHANES 1999–2002. Estimated mean daily total flavonoid intake, 189.7 mg/d, was mainly from flavan-3-ols (83.5%), followed by flavanones (7.6%), flavonols (6.8%), anthocyanidins (1.6%), flavones (0.8%), and isoflavones (0.6%). The flavonoid density of diets increased with age ($P < 0.001$) and income ($P < 0.05$). It was higher in women ($P < 0.001$), Caucasians ($P < 0.001$), and vitamin supplement users ($P < 0.001$) and lower in adults with high levels of nonleisure time physical activity ($P < 0.01$) compared with their counterparts. The greatest daily mean intake of flavonoids was from the following foods: tea (157 mg), citrus fruit juices (8 mg), wine (4 mg), and citrus fruits (3 mg). The proposed relation between flavonoid intake and the prevention of chronic diseases needs further investigation using the estimates introduced in this study. J. Nutr. 137: 1244–1252, 2007.

Introduction

High consumption of fruits and vegetables has been proven to be associated with a lower incidence and mortality rate of various degenerative diseases such as cancer (1,2), cardiovascular disease (3–5), and immune dysfunction (6) in several human cohort and case-control studies. In addition to the vitamins and minerals present in fruits and vegetables, phytochemicals such as flavonoids and other phenolics may contribute to these beneficially protective effects (7).

Flavonoids are the most common and the largest plant polyphenolics obtained from the everyday plant-source diet. Dietary flavonoids are also nutrients and food components that need detailed evaluation, assuming adequate scientific data are available, to establish dietary reference intakes for planning and assessing diets for healthy people (8). Therefore, considerable effort has been made to establish optimal human dietary consumption levels for flavonoids based on their pharmacodynamic effects and to determine flavonoid content in assorted dietary sources (9–11). Nonetheless, inadequate means to estimate dietary intake in a population has delayed the ability to establish the dietary recommendations for an individual and groups of people (8). Assessing dietary intake and behaviors of subpopulation groups is also a key in establishing national food and health policies to sustain national health and productivity. To date, the estimation methods have been poorly established (4,7,12–21) and, thus, the resulting estimated human dietary intake of flavonoid varies widely among studies. Currently we have no consensus on a list of compounds to quantify, priority of food items to assay, or a representative sampling approach of foods considering the large variations among crops (4,7,12,13,22,23). To our knowledge, there has been no published data on the estimated flavonoid intake of the U.S. population.

Recently, the USDA released 2 flavonoid databases (FLDB)[5] (24,25) with an expanded list of foods and their content of 6 flavonoids and their subgroups (26). The database is still incomplete and cannot be used to assess the typical American diet. To overcome the incomplete coverage of typically consumed foods, we expanded FLDB by applying the food code for the same foods that had similar processing or preparation.

This study aimed to estimate flavonoid intake among U.S. adults, to describe total and individual flavonoid intake among U.S. adults and within sociodemographic subgroups, and to document the contribution of specific foods to total and individual

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[2] Supplemental Tables 1–3 are available with the online posting of this paper at jn.nutrition.org.

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[5] Abbreviations used: DR, dietary recall; FLDB, USDA flavonoid database; PIR, poverty income ratio.

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flavonoid intake. The resulting data will provide solid evidence on the role of diet, specifically its flavonoids components, in reducing risks of chronic diseases in the free-living population.

Materials and Methods

Description of FLDB. The USDA database for the Flavonoid Content of Selected Food (24) presents the most abundant 19 individual flavonoid compounds in 6 subgroups based on their chemical structure: flavonols, flavones, flavanones, flavan-3-ols, and anthocyanidins except isoflavones. The 234 selected foods in the dataset include raw and processed fruits and juices, different vegetables, and herbs and edible leaves, dried tea, wine, and beer. The USDA-Iowa State University Database on the Isoflavone Content of Foods (25) was generated by extensive sampling of 108 soy-containing foods and subsequent analysis at Iowa State University. Data for only the most prominent isoflavones and their glucosides were screened for collecting quality data using the expert system described by Mangels et al. (27). The data in the dataset express aglycone equivalents in each food after converting all glucoside forms into aglycone forms by using appropriate ratios of molecular weights and adding them to their respective free-form values to generate mean values for each aglycone form: daidzein, genistein, glycitein, biochanin A, and formononetin.

Two separate FLDB, i.e. 5 flavonoid subgroups and 1 isoflavone subgroup, were combined into 1 flavonoid database. Thus, dietary flavonoid intake was estimated for 6 major flavonoid subgroups and their 24 component flavonoids in each subgroup: flavonols (quercetin, kaempferol, myricetin, isorhamnetin), flavones (luteolin, apigenin), flavanones (eriodictyol, hesperetin, naringenin), flavan-3-ols (catechins, epicatechins, theaflavins, thearubigins), anthocyanidins (cyanidin, delphinidin, malvidin, pelargonidin, peonidin, petunidin), and isoflavones (daidzein, genistein, glycitein, biochanin A, formononetin).

Expansion of flavonoid database. The FLDB lists the food codes for 342 food items. Thus, to estimate the representative intake of flavonoids from food consumption, we assigned the same food code for the food items with similar flavonoid contents but which differed in processing or preparation, such as frozen, drained, boiled, cooked, toasted, baked, steamed, stewed, french-fried, part-fried, oven heated, canned, chopped, sliced, kernels, bottled, water-packed, diet vs. regular packed, prepared, home-prepared, pickled, mashed, hashed, unenriched, microwave treated, salted, brine, sweetened, fat-added, calcium added, saccharine, corn sweetener, flavor-added, alcoholic beverage light vs. regular, low sodium, low calorie, low fat, and reduced fat (28,29). If more than 1 food code applied, we chose the closest properties of processing (boiled, canned, or cooked). In contrast, addition of ascorbic acid, cream, syrup, water, milk, lemon; enriched; physical processing that influences density (diluted, dried, powdered, concentrated, juice, cocktail, flour) (30–32); chemical processing that changes physical and chemical properties (with alkali, brown, granules, flakes, puffs) (33); different kinds of coffee (34–36); with vs. without skin or peel, different color, mature vs. immature, spears, and cultivars (37–39) were not considered for this modification, because these properties have been reported to make marked difference in flavonoid content.

Estimation of dietary intake. Dietary flavonoid intake was estimated based on 24-h dietary recall (DR) of the NHANES 1999–2002 (40,41). The National Center for Health Statistics conducted the survey to obtain nationally representative information on the health and nutritional status of the U.S. population. The most recently released NHANES 1999–2002 sample represents the total civilian, noninstitutionalized population ≥2 mo of age in the 50 U.S. states and the District of Columbia. The NHANES 1999–2002 is composed of NHANES 1999–2000 (40) and NHANES 2001–2002 (41). Every year, ~7000 individuals of all ages are interviewed in their homes; of these, ~5000 complete the health examination component of the survey. All interviewed persons were invited to the Mobile Examination Center, where the 24-h DR was administered. DR data contains all foods and beverages consumed by the respondents except plain drinking water for the previous 24-h time period (midnight to midnight).

FFQ from the NHANES 1999–2000 were used to correlate the frequencies of fruit and fruit juice, vegetable, and wine consumption to the individual and total flavonoids intake.

Inclusion of dietary intake data. A total of 8809 individuals over 19 y of age who completed the 24-h DR and FFQ in the NHANES 1999–2002 were included in this study. Pregnant and nursing women's data were excluded because of the related physiological effect on serum biomarkers. To avoid errors from misreporting, individuals with unreliable or incomplete DR records were excluded as noted by the National Center for Health Statistics (42).

Estimation of individual flavonoid intake. To link NHANES food consumption data with FLDB, the following steps were taken as described in our previous work (43): *1*) convert food items in 24-h DR of NHANES to USDA Standard Reference codes using the food recipe book and the food description data file for NHANES food codes; *2*) adjust weight using moisture content adjustment; *3*) modify code using the USDA food unit conversion search program; and *4*) link these food intake data to the expanded FLDB. By these sequential conversions, a piece of vegetable pizza (NHANES food code 14620310), for example, was converted to specific amounts of mozzarella cheese, parmesan cheese, garlic, soybean oil, olives, mushrooms, onion, green peppers, tomato puree, and salt. The same process was applied to mixed vegetables, hamburgers, sandwiches, soups, and so on. Individual flavonoid intake from selected foods was determined by multiplying the content of the individual flavonoid by the daily consumption of the selected food item. Total intake of individual flavonoids was the sum of individual flavonoid intake from all food sources reported by the 24-h DR. Total flavonoid intake was determined by the summation of the total intake of individual flavonoids.

To test the linear tends in individual and total flavonoid intakes by the consumption of specific food groups, such as fruits and fruit juices, vegetables and vegetable products, wine, and tea, all subjects who did not consume the food group in the 1-d 24-h DR were classified as a group of nonconsumers and all consumers were divided into tertiles by the amount of consumption. Tea included all tea leaf, herbal, and nonspecified teas, brewed, ready-to-drink, instant, powdered, and sweetened teas. Food frequency was collected based on the questionnaire asking "On an average day, how many helpings of (fruits and fruit juices; vegetables) do you eat?" and "How often do you drink wine per month?" All subjects who did not consume the food in the FFQ were designated as a group of nonconsumers and all consumers were divided by the frequency of consumption.

Flavonoid/energy density. Dietary total and individual flavonoid intakes were assessed by daily total intake and energy adjusted intake to address the quantity as well as quality of diet. Dietary flavonoid density of U.S. adults and their sociodemographic subgroups was obtained after adjusting total flavonoid intake per 4186.8 kJ (1000 kcal). The U.S. adult population was also subgrouped by sociodemographic and lifestyle variables: age (19–30, 31–50, 51–70, 70+ y); gender; ethnicity (nonHispanic white; nonHispanic black; Mexican-American; others); poverty income ratios [(PIR) <1.85; ≥1.85]; alcohol consumption (yes, no); smoking (yes, no); nonleisure time physical activity level (1, 2, 3, and 4); and dietary supplement use (yes, no). Alcohol consumption "yes" meant to have at least 12 drinks per year. "Yes" for "current smoking" meant to have smoked cigarettes, cigars, pipes, or used chewing tobacco or snuff at least once during the past 30 d. Nonleisure time physical activity level was defined as daily activities associated with work, housework if a homemaker, going to/from and attending classes if a student, and normal activities throughout a typical day if a retiree or unemployed (1 stands for sitting during the day and not walking very much; 2 for standing or walking a lot during the day but not having to carry or lift things very often; 3 for lifting light loads or having to climb stairs or hills often; 4 for doing heavy work or carrying heavy loads). Vitamin supplement users were those who responded "yes" to the question "Any dietary vitamin supplements taken during last 30 d?".

Dietary sources of total and individual flavonoid intake. We determined the total and individual flavonoid intake from the major sources of diets: fruits and fruit juices, vegetables and vegetable products, and beverages. Beverage consumption was further classified into wine and tea consumption to test whether the flavonoids intake reflects specific types of food consumption.

The contribution of each food or food group to the daily total intake of flavonoids for all persons was calculated by taking the ratio of daily total flavonoids provided by the specific food or food group over the total intake of flavonoids from all foods (44).

Statistical analyses. Arithmetic means of dietary total and individual flavonoid intake of subpopulations grouped by sociodemographic and lifestyle variables were determined. SEM was calculated by the linearization (Taylor series) variance estimation method for population parameters by SUDAAN. Energy adjusted intake was calculated by dividing values by 4186.8 kJ (1000 kcal). Distributions of categorical variables were assessed using a chi-square test. Means for interval scale variables were compared using *t* tests (accounting for the population variance) and ANOVA techniques. *t* Tests and ANOVA were used to test for overall differences of flavonoid intakes by sociodemographic and lifestyle variables such as gender, income, smoking, etc. The trends of flavonoid intakes by the weight and frequency of specific food groups consumed were tested using linear contrasts.

Multivariate linear regression analyses were performed to determine the extent to which energy-adjusted flavonoid intake was explained by dietary behaviors and other sociodemographic factors. We chose independent variables of the regression model based on the significant relations from overall differences and linear trends. The model included the amounts of fruit and vegetable consumption and age as continuous variables and gender, income, and wine and tea consumption as dichotomous variables. Participants were divided into 2 groups according to tea and wine consumption, each based on 24-h DR as consumers vs. nonconsumers.

Results

Evaluation of the expanded flavonoid database. The 24-h DR of 8809 people in NHANES 1999–2002 included 4391 food items. These food items were converted into 2,131 the USDA Standard Reference codes, and then matched with 358 food codes of expanded FLDB. As the result, the subsequent flavonoid intake estimation was based on 87% of fruits and fruit juices, 86% of vegetables, 75% of legumes, and 54% of beverages, and, thus, 45% of all foods recalled in NHANES 1999–2002 (**Supplemental Table 1**).

Whether the consumption of specific food groups or foods influenced total and individual flavonoid intakes was investigated by testing the linear trends in individual and total flavonoid intakes by the consumption of specific food groups such as fruits and fruit juices, vegetables and vegetable products, wine, and tea. Fruit and fruit juices were the most important dietary sources of flavonols, flavanones, anthocyanidins, and isoflavones; vegetables and vegetable products of flavonols and flavan-3-ols; wine of flavonols and anthocyanidins; and tea of flavonols and flavan-3-ols, respectively ($P < 0.001$) (**Table 1**). Subjects' self-reported frequency of food group intake also showed consistent results, i.e. fruits and fruit juice intake with flavanones; vegetable intake with flavonols; and wine intake with flavonols and anthocyanidins ($P < 0.01$) (**Table 2**).

Estimated flavonoid intake. The individual and total flavonoid intakes of the subjects were estimated by combining the USDA flavonoids database and 24-h DR in the NHANES 1999–2002. The daily flavonoid intake in subjects 19+ y was 189.7 ± 11.2 mg (± SD). Flavan-3-ols were major contributors (82.5%) to total flavonoid intake, followed by flavanones (7.6%), flavonols (6.8%), anthocyanidins (1.6%), flavones (0.8%), and isoflavones (0.6%) (**Table 3**). To investigate the disparity in the flavonoid intake levels among different subgroups, the individual and total flavonoid intake of subgroups that were divided by sociodemographic and life style factors were estimated. After adjusting for energy intake, flavonoid density increased with age ($P < 0.001$) and income ($P < 0.05$) and decreased with nonleisure time physical activity level ($P < 0.01$) (**Supplemental Table 2**). It also was higher in women than in men ($P < 0.001$), higher in Caucasians than in other ethnic subgroups ($P < 0.001$), and higher in vitamin supplement users than in nonusers ($P < 0.001$).

Major dietary flavonoid sources. The major dietary sources for the total flavonoids were tea, citrus fruit juices, wine, and citrus fruits. Tea was identified as the most important source, especially for flavan-3-ols and flavonols, contributing 157 mg of daily flavonoid intake. A mixture of grain foods was the major source for flavones; citrus fruit juices for flavanones; wine for anthocyanidins; and legumes for isoflavones (**Supplemental Table 3**). Tea consumption, gender, and ethnicity were strong predictors for flavonoids intake in a multivariate linear model (**Table 4**).

Discussion

Despite the reported importance of health effects of flavonoids, a limited number of studies on the estimation of flavonoid intake have been documented around the world (4,7,12–21) (**Table 5**). These estimates were based on a limited number of foods, selected flavonoid compounds quantified by different analytical methods and different groups of study subjects. For example, Kuhnau (12) reported daily mean flavonoid intake of the U.S. population as 1 g/d. This estimate was based on 5 of 6 total classes of flavonoids, excluding isoflavones, and ~100 flavonoid glycosides. Hertog et al. (4,13,45) assayed 28 vegetables, 12 fruits, and 9 beverages for only 5 flavonoids (quercetin, kaempferol, myricetin, luteolin, and apigenin) by HPLC methods in estimating the total flavonoid intake. In the Zutphen elderly study of 805 men aged 65–84 y, Hertog et al. (45) reported the estimated intake of 26 mg/d of flavonoids from quercetin, kaempferol, myricetin, apigenin, and leuteolin. They also reported that the major sources of intake were tea, onion, and apples. Chun et al. (7) assayed flavonoid contents in 20 vegetables and 14 fruits by spectrophotometry and estimated U.S. per capita consumption. Arts et al. (17) estimated 50 mg of catechin intake, mainly from tea consumption.

The results above show how the estimates can vary widely among studies based on flavonoids considered and foods considered in assessment. Two studies reported by Hertog et al. (13,45) documented similar estimates of flavonoid intake (23 and 26 mg/d, respectively) for the different Dutch population subgroups from 3 flavonols and 2 flavones in commonly consumed fruits, vegetables, and beverages, including tea. However, the other study by Arts et al. (17) reported 2 times higher the amount of flavonoid intake (50 mg/d) for adults in the Netherlands from the single catechin content in fruits, vegetables, and beverages, including tea. These results imply that the total flavonoid intake of the Dutch population might be at least 75 mg/d. Sampson et al. (21) reported that onion is the leading flavonoid source in the US followed by tea and apples. They determined the flavonoid intake from only 3 flavonols and 2 flavones and did not consider that from catechins, major flavonoids in tea, even though their FFQ

TABLE 1 Flavonoid intake of U.S. adults aged 19+ y by food group consumption from 24-h DR in the NHANES 1999–2002[1]

Food group	Amount of intake				P-value[4]
	Nonconsumers[2]	T1[3]	T2	T3	
Fruits and fruit juices					
Intake, *g/d*	0.0	≤124.5	≤300.8	>300.8	
Subject, *n*	2963	1978	1921	1947	
Total flavonoids, *mg/d*	187.4 ± 16.7	186.3 ± 15.3	184.4 ± 15.9	203.3 ± 13.9	0.435
Flavonols, *mg/d*	11.3 ± 0.5	12.6 ± 0.6	13.5 ± 0.6	15.4 ± 0.6	<0.001
Flavones, *mg/d*	0.8 ± 0.2	1.4 ± 0.2	2.4 ± 0.4	2.2 ± 0.9	0.089
Flavanones, *mg/d*	2.1 ± 0.3	4.7 ± 0.3	16.2 ± 0.9	45.2 ± 1.6	<0.001
Flavan-3-ols, *mg/d*	171.4 ± 16.1	164.3 ± 14.7	146.1 ± 15.4	132.7 ± 13.1	0.023
Anthocyanidins, *mg/d*	1.2 ± 0.2	2.6 ± 0.5	4.2 ± 0.8	5.9 ± 1.0	<0.001
Isoflavones, *mg/d*	0.6 ± 0.1	0.7 ± 0.3	2.0 ± 0.4	2.0 ± 0.3	<0.001
Vegetables and vegetable products					
Intake, *g/d*	0.0	≤123.0	≤261.1	>261.1	
Subject, *n*	729	2693	2696	2691	
Total flavonoids, *mg/d*	111.8 ± 16.5	147.4 ± 11.1	194.6 ± 15.4	242.3 ± 20.4	<0.001
Flavonols, *mg/d*	5.5 ± 0.6	8.4 ± 0.4	12.4 ± 0.5	19.2 ± 0.8	<0.001
Flavones, *mg/d*	0.0 ± 0.0	1.7 ± 0.4	1.4 ± 0.3	2.0 ± 0.6	0.003
Flavanones, *mg/d*	12.4 ± 1.6	12.8 ± 0.6	13.9 ± 1.0	17.0 ± 1.0	0.021
Flavan-3-ols, *mg/d*	90.8 ± 15.1	121.5 ± 10.6	162.6 ± 15.0	198.3 ± 19.6	<0.001
Anthocyanidins, *mg/d*	2.2 ± 0.7	2.1 ± 0.4	3.3 ± 0.7	4.1 ± 0.6	0.011
Isoflavones, *mg/d*	0.8 ± 0.4	0.8 ± 0.2	1.1 ± 0.2	1.7 ± 0.4	0.040
Wine					
Intake, *g/d*	0.0	≤27.4	≤206.5	>206.5	
Subject, *n*	8159	217	226	207	
Total flavonoids, *mg/d*	187.8 ± 12.1	169.0 ± 26.0	212.5 ± 41.4	243.2 ± 15.4	0.017
Flavonols, *mg/d*	12.5 ± 0.4	12.6 ± 1.1	15.3 ± 1.6	20.4 ± 0.8	<0.001
Flavones, *mg/d*	1.6 ± 0.3	1.0 ± 0.2	1.6 ± 0.4	1.8 ± 0.6	0.491
Flavanones, *mg/d*	14.2 ± 0.7	19.7 ± 2.5	15.0 ± 2.0	15.8 ± 2.4	0.990
Flavan-3-ols, *mg/d*	156.8 ± 11.8	132.1 ± 24.9	166.9 ± 39.9	161.5 ± 15.4	0.538
Anthocyanidins, *mg/d*	1.5 ± 0.4	0.8 ± 0.1	13.0 ± 1.3	41.3 ± 1.7	<0.001
Isoflavones, *mg/d*	1.1 ± 0.2	2.8 ± 1.2	0.8 ± 0.3	2.2 ± 1.0	0.702
Tea					
Intake, *g/d*	0.0	≤296.0	≤606.8	>606.8	
Subject, *n*	6934	641	613	621	
Total flavonoids, *mg/d*	32.6 ± 1.5	191.5 ± 10.4	467.4 ± 9.1	1237.0 ± 32.0	<0.001
Flavonols, *mg/d*	7.3 ± 0.2	13.2 ± 0.4	22.7 ± 0.6	50.2 ± 1.1	<0.001
Flavones, *mg/d*	1.5 ± 0.3	1.4 ± 0.5	1.7 ± 0.4	2.3 ± 0.9	0.356
Flavanones, *mg/d*	14.6 ± 0.7	17.5 ± 2.3	14.2 ± 1.7	11.4 ± 1.1	0.021
Flavan-3-ols, *mg/d*	5.1 ± 0.4	153.6 ± 8.7	424.6 ± 9.3	1168.8 ± 31.3	<0.001
Anthocyanidins, *mg/d*	3.1 ± 0.4	4.0 ± 1.3	3.4 ± 0.9	2.1 ± 0.5	0.102
Isoflavones, *mg/d*	1.1 ± 0.1	1.8 ± 1.2	0.8 ± 0.2	2.3 ± 0.8	0.321

[1] Values are means ± SD.
[2] All subjects who did not consume the food in the 1-d 24-h DR were grouped as nonconsumers and all consumers were divided into tertiles by the amount of consumption.
[3] T1, T2, and T3 stand for the 1st, 2nd, and 3rd tertile, respectively.
[4] *P*-values for linear trend.

included tea. A similar conclusion was derived in the Japanese study by Arai et al. (19), which estimated flavonoid intake from 1 flavone, 4 flavonols, and 2 isoflavones in fruits, vegetables, and green tea, and documented that onion is the major flavonoid source for Japanese without considering catechins from green tea. The flavonoid intake from 4 flavonols and 2 flavones in the present study was 14.5 mg/d (Table 3) and it was compatible with the estimate (12.9 mg/d) by Hertog et al. (4), which was determined from 3 flavonols and 2 flavones for the U.S. population. Therefore, the inclusion of diverse food items consumed and the comprehensive compilation of the composition data on flavonoid compounds are critical to document the representative flavonoid intake levels of a target population.

Dietary habits are often dictated by culture and affect the intake of subgroups and amount of flavonoids (36). In Japan, soy and soy-containing foods are consumed in large quantities and, as a result, isoflavone intake is higher than other flavonoid subclasses (19). Cultural habits remain strong in terms of consumption of soy food among Asian Americans who have immigrated to the US. Their diets contain a modest amount of isoflavones when compared with nonAsian residents in the US (19,36,46).

TABLE 2 Flavonoid intake of U.S. adults aged 19+ y by frequencies of food consumption in the NHANES 1999–2000[1,2]

Food group	Frequency of intake				*P*-value[4]
Fruits and fruit juices					
Frequency of intake, *times/d*	Nonconsumers[3]	1	2	>2	
Subject, *n*	172	671	430	256	
Total flavonoids, *mg/d*	153.9 ± 31.9	173.4 ± 21.8	180.7 ± 21.1	195.0 ± 25.9	0.329
Flavonols, *mg/d*	11.0 ± 1.4	11.8 ± 0.8	12.6 ± 1.0	13.9 ± 1.0	0.073
Flavones, *mg/d*	0.5 ± 0.1	0.8 ± 0.1	1.2 ± 0.3	2.1 ± 1.2	0.176
Flavanones, *mg/d*	4.3 ± 1.2	13.5 ± 1.1	15.5 ± 2.6	26.7 ± 2.6	<0.001
Flavan-3-ols, *mg/d*	136.1 ± 31.1	144.0 ± 21.3	147.3 ± 20.1	145.3 ± 24.7	0.804
Anthocyanidins, *mg/d*	0.4 ± 0.3	2.8 ± 1.1	1.5 ± 0.4	6.7 ± 3.2	0.058
Isoflavones, *mg/d*	1.6 ± 0.9	0.7 ± 0.2	2.6 ± 1.3	0.4 ± 0.2	0.627
Vegetables and vegetable products					
Frequency of intake, *times/d*	Nonconsumers	1	2	>2	
Subject, *n*	151	729	456	194	
Total flavonoids, *mg/d*	143.3 ± 37.6	137.6 ± 15.5	193.6 ± 25.8	270.3 ± 29.7	0.011
Flavonols, *mg/d*	10.7 ± 1.4	10.4 ± 0.8	13.1 ± 1.0	17.0 ± 1.6	0.006
Flavones, *mg/d*	4.3 ± 3.2	0.7 ± 0.1	0.9 ± 0.2	1.0 ± 0.3	0.328
Flavanones, *mg/d*	13.3 ± 5.5	13.7 ± 1.0	15.8 ± 1.3	20.2 ± 2.2	0.110
Flavan-3-ols, *mg/d*	109.8 ± 35.4	109.1 ± 15.7	160.7 ± 25.5	225.4 ± 28.5	0.015
Anthocyanidins, *mg/d*	4.6 ± 2.9	2.3 ± 1.0	1.7 ± 0.5	5.9 ± 2.6	0.693
Isoflavones, *mg/d*	0.7 ± 0.6	1.4 ± 0.8	1.4 ± 0.7	0.9 ± 0.3	0.865
Wine					
Frequency of intake, *times/mo*	Nonconsumers	1	2–4	>4	
Subject, *n*	2992	297	360	295	
Total flavonoids, *mg/d*	186.2 ± 18.5	171.9 ± 19.9	171.1 ± 29.9	278.4 ± 45.0	0.047
Flavonols, *mg/d*	12.2 ± 0.6	11.9 ± 0.9	13.3 ± 1.1	17.8 ± 1.8	0.002
Flavones, *mg/d*	1.5 ± 0.3	0.8 ± 0.3	4.1 ± 3.0	0.7 ± 0.1	0.775
Flavanones, *mg/d*	12.1 ± 1.0	15.5 ± 2.6	16.5 ± 1.6	15.2 ± 1.3	0.037
Flavan-3-ols, *mg/d*	158.4 ± 18.4	139.7 ± 20.6	131.0 ± 27.2	229.1 ± 42.6	0.109
Anthocyanidins, *mg/d*	1.1 ± 0.4	1.0 ± 0.3	4.1 ± 1.2	13.7 ± 1.4	<0.001
Isoflavones, *mg/d*	0.9 ± 0.3	2.9 ± 1.3	2.1 ± 0.9	2.0 ± 0.9	0.326

[1] Values are means ± SD.
[2] Food frequency was collected based on the questionnaire asking ''On an average day, how many helpings of (fruits and fruit juices; vegetables) do you eat?'' and ''How often do you drink wine per month?''.
[3] All subjects who did not consume the food in the FFQ were grouped as nonconsumers and all consumers were divided by the frequency of consumption.
[4] *P*-values for linear trend.

Lower socioeconomic groups in the US consume inadequate amounts of vegetables, fruit, and whole-wheat bread. Their diets contain lower amounts of essential nutrients, antioxidant vitamins, and flavonoids than those of higher socioeconomic groups. Kirkpatrick and Tarasuk (47) attributed this socioeconomic difference in the US to constrained access to these foods. The present study demonstrated that there was considerable difference in flavonoid intake among different sociodemographic subgroups by age, gender, ethnicity, and income levels. Whether this disparity in flavonoid intake influences the different levels of prevalence of chronic diseases among various sociodemographic subgroups needs further study.

We identified tea as a major flavonoid source in the U.S. diet, which is in accord with previous studies that reported tea consumption as the major source of flavonoids intake (17,45,48). Although benefits of tea consumption are well documented in preventing various chronic diseases (49–51), we know little about the characteristics and other dietary behaviors of tea consumers in the US.

The mean flavonoid intake (189.7 mg/d) of this study was much higher than in the previous reports for the U.S. population (4,7,21) and also higher than in other studies reported in Denmark (14), Finland (15,16), the Netherlands (13), or Japan (19). A study conducted for the Australian population, which estimated flavonoid intake from 15 flavonoids except isoflavones, showed similar results to our estimates (128 mg/d) (48). Even though this estimate was based on only 24 healthy young women, the result implies that our estimates collected from the general U.S. population, determined by summating 24 flavonoids, are within a reasonable range.

The results of this study should be interpreted based on several assumptions: first, the USDA food composition databases were constructed based on U.S. representative food samples, including varying cultivars, geographic origins, growing seasons, agricultural practices, and analytical methods. Second, this study focused on flavonoid intake and did not consider individual bioavailability and metabolism in the human body or changes during processing and food preparation. Third, this study included major flavonoids of 6 flavonoids subgroups consisting of 24 individual flavonoid compounds. Fourth, even though within-person variability might cause a single 24-h DR to be an unreliable indicator of the diet or nutritional status of an individual, this method can produce adequate estimates of average intake that can be useful for contrasting the dietary

TABLE 3 Daily dietary total and individual flavonoid intakes of U.S. adults aged 19+ y and its subgroups by sociodemographic and lifestyle factors in the NHANES 1999–2002[1]

Subgroups	Stratified sample	Flavonoid intake							
		Flavonols	Flavones	Flavanones	Flavan-3-ols	Anthocyanidins	Isoflavones	Total	*P*-value[2]
Survey phase	*n*				*mg/d*				
Phase I (1999–2000)	4175	12.8 ± 0.6	1.6 ± 0.4	13.3 ± 0.9	161.7 ± 18.8	2.6 ± 0.5	1.3 ± 0.3	193.3 ± 19.0	
Phase II (2001–2002)	4634	12.9 ± 0.5	1.5 ± 0.2	15.5 ± 0.9	152.0 ± 13.2	3.6 ± 0.7	1.1 ± 0.1	186.6 ± 13.9	
Gender									
All	8809	12.9 ± 0.4	1.6 ± 0.2	14.4 ± 0.6	156.5 ± 11.3	3.1 ± 0.5	1.2 ± 0.2	189.7 ± 11.6	0.594
Men	4461	13.7 ± 0.4	1.5 ± 0.2	15.9 ± 0.7	157.7 ± 13.5	2.9 ± 0.4	1.1 ± 0.2	192.7 ± 13.7	
Women	4348	12.1 ± 0.5	1.7 ± 0.4	13.1 ± 0.7	155.4 ± 11.3	3.4 ± 0.6	1.3 ± 0.2	186.9 ± 11.8	
All, *y*									
19–30	1873	11.6 ± 0.6	1.4 ± 0.4	15.3 ± 1.2	142.9 ± 16.5	1.2 ± 0.3	1.2 ± 0.4	173.5 ± 17.5	0.008
31–50	2835	13.2 ± 0.5	1.8 ± 0.5	13.2 ± 0.9	159.0 ± 12.7	3.5 ± 0.6	1.3 ± 0.2	192.0 ± 13.0	
51–70	2582	14.2 ± 0.6	1.4 ± 0.3	15.5 ± 1.2	178.9 ± 16.4	4.2 ± 0.7	1.2 ± 0.2	215.4 ± 16.8	
70+	1519	10.8 ± 0.4	1.5 ± 0.3	15.0 ± 1.0	119.3 ± 11.4	2.6 ± 0.4	0.9 ± 0.2	150.0 ± 11.4	
Men, *y*									
19–30	1001	13.4 ± 0.8	1.1 ± 0.5	16.9 ± 1.9	162.9 ± 23.6	0.9 ± 0.3	1.3 ± 0.6	196.5 ± 24.5	0.036
31–50	1426	14.0 ± 0.6	1.4 ± 0.3	14.3 ± 1.2	157.0 ± 13.9	3.1 ± 0.5	1.2 ± 0.3	190.9 ± 14.0	
51–70	1288	14.5 ± 0.6	1.8 ± 0.5	16.9 ± 1.4	169.9 ± 18.6	4.1 ± 0.9	0.9 ± 0.2	208.0 ± 18.7	
70+	746	10.7 ± 0.5	2.1 ± 0.8	17.7 ± 1.5	111.4 ± 13.6	3.0 ± 0.6	0.6 ± 0.2	145.6 ± 13.9	
Women, *y*									
19–30	872	9.6 ± 0.6	1.7 ± 0.7	13.4 ± 1.3	120.0 ± 16.6	1.4 ± 0.5	1.0 ± 0.3	147.2 ± 17.3	0.011
31–50	1409	12.5 ± 0.7	2.2 ± 0.9	12.2 ± 1.2	161.0 ± 15.8	4.0 ± 0.8	1.3 ± 0.3	193.1 ± 16.6	
51–70	1294	13.9 ± 0.7	1.1 ± 0.1	14.1 ± 1.4	187.2 ± 20.3	4.3 ± 0.9	1.6 ± 0.4	222.2 ± 21.1	
70+	773	10.8 ± 0.6	1.1 ± 0.2	13.2 ± 0.9	124.4 ± 13.0	2.3 ± 0.5	1.1 ± 0.4	152.8 ± 13.3	
Ethnicity									
Non-Hispanic White	4212	14.1 ± 0.5	1.8 ± 0.3	13.0 ± 0.7	183.0 ± 14.1	3.8 ± 0.6	1.2 ± 0.2	216.8 ± 14.6	<0.001
Non-Hispanic Black	1762	9.1 ± 0.4	1.1 ± 0.2	18.0 ± 1.2	99.9 ± 9.9	1.3 ± 0.3	1.2 ± 0.3	130.6 ± 9.7	
Mexican-American	2141	11.0 ± 0.5	1.3 ± 0.2	19.8 ± 1.2	62.9 ± 9.4	1.0 ± 0.4	0.8 ± 0.2	96.8 ± 9.6	
Others	694	9.8 ± 0.7	0.9 ± 0.2	17.4 ± 1.3	94.0 ± 16.7	1.5 ± 0.6	1.7 ± 0.4	125.3 ± 18.1	
PIR[3]									
<1.0	1503	10.1 ± 0.5	0.9 ± 0.2	12.8 ± 1.1	105.5 ± 12.5	1.0 ± 0.3	0.5 ± 0.1	130.8 ± 12.7	<0.001
1.0–1.3	820	11.2 ± 0.6	1.5 ± 0.5	11.5 ± 1.2	152.9 ± 16.9	0.3 ± 0.1	0.8 ± 0.4	178.3 ± 17.5	
1.3–1.85	1078	10.5 ± 0.7	1.6 ± 0.6	12.7 ± 1.2	119.0 ± 17.0	1.3 ± 0.4	0.5 ± 0.1	145.6 ± 17.6	
≥1.85	4496	14.3 ± 0.5	1.8 ± 0.3	15.3 ± 0.8	176.6 ± 14.0	4.3 ± 0.6	1.5 ± 0.2	213.7 ± 14.2	
Alcohol consumption[4]									
No	2531	11.2 ± 0.4	1.6 ± 0.3	13.6 ± 0.9	134.2 ± 11.4	1.2 ± 0.4	1.2 ± 0.2	163.0 ± 12.1	0.004
Yes	5422	13.7 ± 0.4	1.4 ± 0.2	14.5 ± 0.7	167.4 ± 13.4	4.0 ± 0.5	1.2 ± 0.2	202.1 ± 13.6	
Current smoking[5]									
No	4247	12.8 ± 0.4	1.6 ± 0.4	15.8 ± 0.8	154.6 ± 12.1	3.1 ± 0.6	1.5 ± 0.3	189.3 ± 12.6	0.884
Yes	4088	13.1 ± 0.5	1.6 ± 0.2	13.0 ± 0.7	159.7 ± 13.9	3.2 ± 0.5	0.9 ± 0.1	191.4 ± 14.3	
Nonleisure time physical activity level[6]									
1	2224	12.6 ± 0.6	1.4 ± 0.3	14.2 ± 1.3	160.8 ± 12.9	2.7 ± 0.4	1.3 ± 0.3	192.9 ± 13.3	0.928
2	4638	12.8 ± 0.4	1.3 ± 0.2	14.7 ± 0.8	156.0 ± 12.9	3.4 ± 0.7	1.2 ± 0.3	189.4 ± 13.3	
3	1349	13.4 ± 0.7	2.8 ± 1.1	15.2 ± 1.0	146.3 ± 16.1	3.7 ± 0.6	1.0 ± 0.2	182.3 ± 17.1	
4	586	12.9 ± 1.2	0.8 ± 0.2	12.1 ± 1.5	167.3 ± 31.0	1.5 ± 0.6	1.3 ± 0.5	195.9 ± 31.6	
Vitamin supplement use[7]									
No	4994	12.0 ± 0.4	1.3 ± 0.2	13.4 ± 0.8	141.5 ± 11.5	2.1 ± 0.3	0.8 ± 0.2	171.1 ± 11.6	<0.001
Yes	3719	14.0 ± 0.5	1.9 ± 0.4	15.6 ± 0.8	174.6 ± 13.5	4.3 ± 0.7	1.6 ± 0.3	211.9 ± 13.9	

[1] Values are means ± SD.
[2] *P*-values are for overall difference by *t* test among male and female, age subgroups, age subgroups in male and female, ethnicity, income levels, alcohol consumption, smoking, nonleisure time physical activity level, and dietary supplement use.
[3] Ratio of the median family income over the poverty index. A PIR of ≤1.30 is required to be eligible for food assistance programs.
[4] Alcohol consumption: yes meant to have at least 12 alcohol-containing drinks per year.
[5] Current smoking: yes meant to have smoked cigarettes, cigars, pipes, or used chewing tobacco or snuff at least once during the past 30 d.
[6] Nonleisure time physical activity level: daily activities including work, housework if a homemaker, going to and attending classes if a student, and normal activities throughout a typical day if a retiree or unemployed. 1 = sitting during the day and not walking very much; 2 = standing or walking about a lot during the day but not having to carry or lift things very often; 3 = lifting a light load or having to climb stairs or hills often; and 4 = doing heavy work or carrying a heavy load.
[7] Vitamin supplement use: yes meant to be taking dietary vitamin supplements.

TABLE 4 Multivariate predictive model for energy adjusted flavonoid intakes of U.S. adults aged 19+ y in the NHANES 1999–2002

Variables	Flavonoid intake,[1] *mg/(1000 kcal·d)* Slope[2] (β coeff.)	*P*-value[3]
Fruit consumption, *g/d*	0.004	0.636
Vegetable consumption, *g/d*	−0.01	0.427
Tea consumption (nonconsumer = 0; consumer = 1)	355.63	<0.001
Wine consumption (nonconsumer = 0; consumer = 1)	6.65	0.556
Age, *y*	0.08	0.572
Gender (men = 0; women = 1)	20.10	0.007
Ethnicity (nonwhite = 0; white = 1)	12.33	0.027
Income level [(PIR < 1.85) = 0; (PIR ≥ 1.85) = 1)]	4.97	0.439

[1] Energy adjusted flavonoid intake was obtained by dividing flavonoid intake by 1000 kcal (4186.8 kJ).
[2] Regression coefficient.
[3] *P*-value from *t* test for regression coefficient (β coeff.) is 0.
[4] Model $R^2 = 0.321$.

status of population subgroups with different levels of risk factors for certain diseases (52).

The real flavonoid intake level of U.S. adults may be higher than this estimation when the flavonoid intake from herbal and isoflavone supplements, which are prevalent in the US, is considered. In addition, the estimates may be increased if the USDA flavonoid database is updated to cover more comprehensive food commodities consumed in the US.

The estimation of total antioxidant intake, which is the summation of antioxidant capacities not only from flavonoids but also from antioxidant vitamins such as vitamins C and E and carotenes consumed through diet and dietary supplement use, is needed to assess the total antioxidant intake levels and link them to the risk of certain diseases. Following the oxidation hypothesis of atherosclerosis, the role of antioxidant vitamins, i.e. carotenoids and vitamins C and E, has been investigated in a large number of epidemiological, clinical, and experimental studies (53–55). An inverse relation between plasma levels of these vitamins individually and biomarkers of oxidative stress and inflammation in healthy adults and in patients with myocardial infarction or stroke has been reported recently (56,57). The mechanisms by which these vitamins act as antiinflammatory agents have also been proven through in vivo and in vitro animal studies (58,59). In contrast, however, human clinical trials of other antioxidant intakes show inconsistent results regarding the ability of antioxidants to reduce systemic and vascular inflammation (53,60). These findings are puzzling, because many of the antioxidants were consumed at levels far beyond those consumed commonly by the free-living population through diets and/or supplements.

These inconclusive results may be due to differences in antioxidant compounds, strengths of antioxidant properties, doses, incomplete estimation of dietary antioxidants of their diets (especially overlooking the potency of polyphenolic antioxidants), and characteristics of study subjects that included patients with high levels of oxidative stress or depleted natural antioxidant defense systems (61,62).

Estimating dietary intake of flavonoids in the U.S. population has been very limited due to lack of data on the flavonoid composition of foods. This study is the first step toward generating the baseline data of flavonoid intake of U.S. adults and subgroups and will be followed by an assessment of the total antioxidant intake.

TABLE 5 Estimated flavonoid intake in several countries

Country	Subjects[1], *n* (age)	Diet data[1]	Analytical method	Flavonoids[1]	Mean flavonoid intake, *mg/d*
Denmark (14)	Danish Household Consumption Survey	Dietary history	Estimation from previous publications	3 Flavanones 1 Flavone 2 Flavonols	23–46
Finland (15)	2748 M 2385 W (30–69 y)	28 V, 9 F	HPLC	Q,K,M,A,L (Netherlands)	3.4 (median)
Finland (16)	10,054	94 (V, F, B)	HPLC	3 Flavanones 2 Flavone 4 Flavonols	24
Netherlands (13)	4112 (>19 y)	49 (28 V, 12 F, 9 B)	HPLC	Q,K,M,A,L	23
Zutphen, Netherlands (45)	804 M (65–84 y)	49 (28 V, 12 F, 9 B)	HPLC	Q,K,M,A,L	26
Netherlands (17)	6200 (1–97 y)	27 V, 24 F, 26 B	HPLC	Catechin	50
Netherlands (18)	17,357 W (50–69 y)	FFQ	Estimation from previous publications and food manufacturers	4 Isoflavones	<1
Japan (19)	115 W (29–78 y)	18 V, 8 F, 1 B	HPLC	1 Flavone 4 Flavonols 2 Isoflavone	63
US (4)	12,763 M (40–59 y)	49 (28 V, 12 F, 9 B)	HPLC	Q,K,M,A,L	12.9
US (20)	964 W (postmenopausal)	FFQ	Estimation from previous publications	4 Isoflavones	0.154 (median)
US (21)	37,886 M 78,886 W	FFQ	HPL	Q,K,M,A,L	20–22
US (7)	Per capita consumption[2]	20 V, 14 F	Spectrophotometric method	Total flavonoids	103 CE[1]

[1] V, vegetables; F, fruits; B, beverages; Q, quercetin; K, kaempferol; M, myricetin; A, apigenin; L, luteolin; M, men; W, women; CE, catechin equivalent.
[2] Food intake estimates are based on USDA per capita consumption.

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