

Original Research

Whole-Grain Consumption Is Associated with Diet Quality and Nutrient Intake in Adults: The National Health and Nutrition Examination Survey, 1999-2004

CAROL E. O'NEIL, PhD, MPH, RD, LDN; THERESA A. NICKLAS, DrPH; MICHAEL ZANOVEC, MS; SUSAN CHO, PhD

ABSTRACT

Background The consumption of whole grains and its association with nutrient intake has not been assessed in a recent nationally representative population.

Objective To examine the association of consumption of whole grains, using the new whole-grain definition, with diet quality and nutrient intake in a recent, nationally representative sample of adults.

Design Secondary analysis of cross-sectional data from 1999-2004 National Health and Nutrition Examination Survey.

Participants and methods Adults aged 19 to 50 years ($n=7,039$) and aged 51 years and older ($n=6,237$).

Main outcome measures Participants were divided into four whole-grain consumption groups: ≤ 0 to <0.6 , ≥ 0.6 to <1.5 , ≥ 1.5 to <3.0 , and ≥ 3.0 servings (ounce equivalents)/day. Macro- and micronutrient intakes and diet quality, using the Healthy Eating Index, were determined for each group.

Statistical analyses Sample weights were applied. The percentages of adults in whole-grain consumption groups were calculated. The covariates used were energy, ethnicity, sex, and age. Least-square means were calculated. P for linear trend analysis was determined using whole-grain intake as a linear covariate. A P value of ≤ 0.05 was considered significant.

Results Adults aged 19 to 50 and 51+ years consumed a mean of 0.63 and 0.77 servings of whole grains per day, respectively. For both age groups, diet quality and intake

of energy, fiber, and polyunsaturated fatty acids were significantly higher in those consuming the most servings of whole grains. Intake of total sugars (19 to 50 year age group only), added sugars, saturated fatty acids, monounsaturated fatty acids, and cholesterol was significantly lower in those consuming the most servings of whole grains. Intake of all micronutrients, except vitamin B-12 and sodium, was higher among individuals who consumed the most servings of whole grains.

Conclusions Overall consumption of whole grains in the US population was low using the recently updated whole-grain definition. Adults who consumed the most servings of whole grains had better diet quality and nutrient intakes.

J Am Diet Assoc. 2010;110:1461-1468.

In the United States, wheat, oats, rice, maize, and barley are the most commonly consumed whole grains, with wheat comprising 66% to 75% of the total (1). The majority of grains consumed in the United States are refined grains (2-6) rather than whole grains. Whole grains include cereal grains that consist of the intact, or ground, cracked, or flaked fruit of the grains whose principal components are present in the same proportions as they exist in the intact grain (7,8). Whole grains are nutrient-dense foods composed of starch; nonstarch polysaccharides; protein; lipids; B vitamins, including thiamin, niacin, riboflavin, and panthothenic acid; vitamin E; minerals, including calcium, magnesium, potassium, phosphorus, iron, and sodium; and flavonoids and other phytochemicals (1,9,10).

Consumption of whole grains, unlike consumption of refined grains, has been associated with a lower risk of cardiovascular disease and stroke (11,12), hypertension (5,11), insulin sensitivity (13), type 2 diabetes mellitus (14), metabolic syndrome (15), obesity (16), and some types of cancer (17). The mechanisms of these beneficial effects are not clear, and components of whole grains may work alone or synergistically to provide health benefits (1,18).

The 2005 Dietary Guidelines Advisory Committee recommended that at least three servings of whole grains per day be consumed by healthy individuals (19). The basis of this recommendation was that consumption of three or more servings of whole grain was associated with 20% to 30% reduced risk of coronary heart disease (12,20). This is in agreement with the recommendation promulgated by Healthy People 2010 to "increase the

C. E. O'Neil is Class of 1941 alumni professor, and M. Zanovec is a research associate, Louisiana State University Agricultural Center, School of Human Ecology, Baton Rouge, LA. T. A. Nicklas is a professor, Department of Pediatrics, USDA/ARS Children's Nutrition Research Center at Baylor College of Medicine, Houston, TX. S. Cho is a statistician, NutraSource, Clarksville, MD.

Address correspondence to: Carol E. O'Neil, PhD, MPH, RD, LDN, Louisiana State University AgCenter, School of Human Ecology, Baton Rouge, LA 70803.

E-mail: coneil1@lsu.edu

Manuscript accepted: April 19, 2010.

Copyright © 2010 by the American Dietetic Association.

0002-8223/\$36.00

doi: 10.1016/j.jada.2010.07.012

proportion of persons aged 2 years and older who consume at least six daily servings of grain products, with at least three being whole grains.” (21). The US Food and Drug Administration allows health claims for whole-grain foods that contain $\geq 51\%$ whole-grain ingredient(s) by weight per reference amount customarily consumed (22). Determining whole-grain intake has been difficult; until recently, there was no consistent definition of whole grains, and studies quantifying intake or assessing health effects have used different definitions (7,23,24). Jacobs and colleagues (25) recommended a definition of whole-grain foods as those with 25% or more whole grain or bran content by weight. Several epidemiologic studies have used this definition (11,26); however, the amount of whole grains in each serving can vary considerably, and this method did not separate bran content added during processing. Jensen and colleagues (27) calculated whole-grain intake by determining the whole-grain content of all grain foods according to the dry weight of whole-grain ingredients; in that study whole-grain intake was calculated with and without bran and germ. A new definition of whole grain, recently applied to the MyPyramid Equivalents Database (MPED), excludes added bran and pearled barley; most published studies have not used this newer definition.

The problem of quantifying whole-grain intake, and the subsequent health effects, has also been complicated by the use of different diet assessment instruments (11,16,26) used in observational studies and sometimes by participants’ understanding of whole grains when dietary intake data were collected. The US Department of Agriculture’s (USDA) Pyramid Servings Database provides quantified measures of whole-grain foods (28), and this database now provides information with and without added bran and pearled barley.

Historically, consumption of whole grains has been low. Using data from the Continuing Survey of Food Intake by Individuals, Cleveland and colleagues (2) showed that American adults consumed an average of 6.7 servings of grain products per day; however, only 1.0 serving was from whole grain. In that study, only 8% of individuals consumed at least three servings of whole grain per day. Low intake of whole grains has been shown for all ethnic and income groups (4). More recently, using data from the 1999-2000 National Health and Nutrition Examination Survey (NHANES), it was shown that only 6% of women consumed three or more servings of whole grain and that 30% of the final sample consumed no whole grains at all on the day of the recall (16). Data from 2001-2002 NHANES also showed that $<10\%$ of grain products consumed were whole grains (29).

Studies looking at nutrient intake related to whole grains are limited, either in the population used or in the number of nutrients examined and they have used an older definition of whole grains (24); however, the studies have suggested there is improved overall nutrient intake when whole grains are a part of the diet when compared to refined grains (3,5,15,27,30). The purpose of this study was to examine the relationship between whole-grains consumption, using the new definition for whole grain, and diet quality and nutrient intake in a recent, nationally representative sample of adults.

PARTICIPANTS AND METHODS

Data Collection

The continuous NHANES is a cross-sectional survey that collects data about the nutrition and health status of the US population using a complex, multi-stage, probability sampling design. Data are released in 2-year increments; and as recommended by NHANES, the data sets from 1999-2000, 2001-2002, and 2003-2004 were combined (31) and analyzed.

For data collection years 1999-2002, a single multiple-pass 24-hour dietary recall was conducted during the interview using computer-assisted software to record dietary intake data from participants (32). In 2003-2004, 2 days of intake were collected; however, for this study, only the data from the interview administered recall (first recall) was used to ensure consistency of intake methodology for this study. Detailed descriptions of the dietary interview methods are provided in the NHANES Dietary Interviewer’s Training Manual, which includes pictures of the Computer-Assisted Dietary Interview system screens, measurement guides, and charts used to collect dietary information (33).

Participants and Whole-Grain Consumption Categories

The NHANES data collected during 1999-2004 were used in a secondary analysis to examine the relationship between whole-grain consumption and diet quality and nutrient intake in adults 19 to 50 years of age ($n=7,039$) and 51 years of age and older ($51+$) ($n=6,237$). These age groups were selected based on the Dietary Reference Intake (DRI) age groupings (34-36). Pregnant and lactating women ($n=993$) were excluded from the analyses. In addition, there were six foods that were introduced in 2003 that could contain whole grains; however, there was no information to calculate the whole-grain content of these foods. The foods included Milk n’ Cereal bar (General Mills, Minneapolis, MN), several character cereals, Berry Burst Cheerios (General Mills), Fruit Harvest cereal (Kellogg, Battle Creek, MI), and Optimum Nature’s Path (Nature Path’s Foods, Richmond, BC, Canada). The 31 adults who consumed at least one of these six products were excluded from the sample. Due to the nature of the analysis (secondary data analysis), and the lack of personal identifiers, this study was deemed exempt by the Institutional Review Board of the Louisiana State University AgCenter.

Participations were categorized into one of four whole-grain consumption groups: ≥ 0 to <0.6 servings, ≥ 0.6 to <1.5 servings, ≥ 1.5 to <3.0 servings, and ≥ 3.0 servings/day (ounce equivalents). The cutoffs and number of groupings were based on enough groupings so that effects were relatively constant within each group, groupings that contained larger numbers of observations to allow detection of differences, and groupings that covered distinct ranges that can be seen relative to common eating habits and recommendations.

Whole-grain intake was calculated using the new definition for whole grains (excluding added bran and pearled barley) as outlined by the USDA Pyramid servings database (28). An ounce equivalent is a comparable amount of various foods used as a standard of comparison within the grain food group (28). An ounce equivalent (one serving)

of grains is the amount of food considered equivalent to ½ c cooked rice, pasta, or cooked cereal; 1 oz dry pasta or rice; one slice bread; one small muffin (1 oz); and, 1 c ready-to-eat cereal flakes.

The MPED for USDA Survey Food Codes, versions 1 (24) and 2 (38), were used in NHANES 1999-2002 and 2003-2004, respectively, to calculate whole-grain intake. The MPED is currently the only database available that provides quantified measures of whole-grain foods with separate tables based on the old and new (without bran and pearled barley) definitions for whole grain. The MPED food data files contain the number of servings (or ounce equivalents) per 100 g food by 32 MyPyramid food groups, three of which include whole grain, non-whole grain, and total grain.

Nutrient Analysis

The USDA Food and Nutrient Database for Dietary Studies, version 1 and version 2, were used in NHANES, 2001-2002 and 2003-2004, respectively. The USDA 1994-98 Survey Nutrient Database was used to process the dietary interview data in NHANES, 1999-2000. In the original release of NHANES, 1999-2000, data on vitamin E intake data were only available in milligrams α-tocopherol equivalents and only total folate intake data were available. Currently, DRIs for vitamin A, vitamin E, and folate are expressed as micrograms retinol activity equivalents, milligrams α-tocopherol, and dietary folate equivalents, respectively (34-36). The special database released by USDA to determine vitamin E as milligrams α-tocopherol (37) was used. The Food and Nutrient Database for Dietary Studies was used to append the intakes of folate and total sugars to the NHANES, 1999-2000, database. Added sugars food composition data were obtained from the Pyramid Servings Database for USDA Survey Food Codes, version 2.0 (38). Added sugars were defined by the USDA as white sugar, brown sugar, raw sugar, corn syrup, corn syrup solids, high fructose corn syrup, malt syrup, maple syrup, pancake syrup, fructose sweetener, liquid fructose, honey, molasses, anhydrous dextrose, crystal dextrose, and dextrin that are eaten separately or used as ingredients in processed or prepared foods.

The Healthy Eating Index (HEI) was calculated using a Statistical Analysis Software (SAS) template (39). To calculate HEI, “discretionary solid fat” and “discretionary oil” are needed. The MPED (version 2), which was used to calculate the new definition of whole grain, only provides “Total Discretionary Fats” as a single group. To overcome this issue, a ratio of “Discretionary Oil to Discretionary Solid Fat” was created for each food using the MPED (version 1), which has these fats separated.

Statistical Analysis

Sample-weighted data were used in all statistical analyses, and all analyses were performed using SUDAAN (release 9.0.1, 2005, Research Triangle Institute, Research Triangle Park, NC) using a modified 6-year weight sample (40). A 6-year weight variable was created by assigning two thirds of the 4-year weight for 1999-2002 if the person was sampled in 1999-2002 or assigning one

Table 1. The number of servings of whole grain consumed by adults, according to data from the 1999-2004 National Health and Nutrition Examination Survey

Servings of Whole Grain	Age (y)			
	19-50 (n=7,039)		51+ (n=6,237)	
	0.63		0.77	
Mean	n	%	n	%
≥3.0	341	4.8	413	6.6
≥1.5 to <3.0	678	9.6	761	12.2
≥0.6 to <1.5	943	13.4	691	11.0
≥0 to <0.6	5,077	72.1	4,372	70.1

third of the 2-year weight for 2003-2004 if the person was sampled in 2003-2004 (40). The covariates used were energy, sex, ethnicity, and age, which were obtained directly from the NHANES datasets. The sample-weighted percentages (and standard error of the percentages) of adults in whole-grain consumption groups were calculated using PROC CROSSTAB of SUDAAN. Unadjusted means and standard errors were also calculated using PROC DESCRIPT of SUDAAN. Least-square means and standard errors were calculated using PROC REGRESS of SUDAAN. *P* for trend was calculated by using SUDAAN with whole-grain intake as a linear covariate. A *P* value of ≤0.05 was considered significant.

RESULTS

Servings of Whole Grains Consumed

Table 1 shows the mean number of whole grains consumed by the two age groups. Adults aged 19 to 50 years consumed an average of 0.63 servings of whole grains per day, whereas adults 51+ years consumed an average of 0.77 servings of whole grains per day. Only 4.8% and 6.6% of individuals in these age groups, respectively, consumed the recommended number of servings (three or more) daily. Adults aged 19 to 50 years and 51 years and older, 72.1% and 70.1%, respectively, consumed 0.6 servings of whole grain or less.

Mean HEI and Nutrient Intakes

For adults aged 19 to 50 years and 51 years and older, mean HEI scores were significantly higher in those with higher consumption of whole grains than in those consuming fewer servings (Tables 2 and 3). Intakes of energy, carbohydrates, and fiber were all significantly higher when more servings of whole grains were consumed. Intake of added sugars, saturated fatty acids, monounsaturated fatty acids, and cholesterol showed a significant decreasing trend with an increased number of servings of whole grains consumed. For adults aged 19 to 50 years and 51+ years, intakes of the micronutrients, except vitamin B-12 and sodium, were higher when more servings of whole grains were consumed (Tables 2 and 3).

DISCUSSION

These data indicate that although overall consumption of whole grain in the US population is low, consumption of

Table 2. Diet quality and adjusted^a nutrient intake of adults aged 19 to 50 y by whole-grain consumption group, according to data from the 1999-2004 National Health and Nutrition Examination Survey

Nutrient	No. of Servings										P for trend
	Total Population		≥0 to <0.6		≥0.6 to <1.5		≥1.5 to <3.0		≥3.0		
	n=7,039		n=5,077		n=943		n=678		n=341		
	LSM ^b	LSSE ^c	LSM	LSSE	LSM	LSSE	LSM	LSSE	LSM	LSSE	
Macronutrient											
Whole-grain servings	0.71	0.02	0.09	0.00	1.01	0.01	2.12	0.02	4.65	0.11	—
Healthy Eating Index	49.19	0.19	46.49	0.21	53.04	0.48	55.45	0.56	59.23	0.89	<0.0001
Energy ^d (kcal)	2,413.02	14.07	2,340.46	17.26	2,468.56	36.78	2,609.04	41.75	2,753.48	56.92	<0.0001
Protein (g)	87.79	0.41	88.01	0.53	88.52	1.01	86.69	1.32	85.33	1.73	0.1162
Carbohydrate (gm)	297.59	1.06	292.37	1.39	302.28	2.61	307.04	3.12	329.43	4.46	<0.0001
Fiber (g)	15.67	0.13	13.85	0.13	16.89	0.30	20.33	0.51	25.11	0.69	<0.0001
Total sugar (g)	145.16	1.07	146.72	1.42	144.29	2.70	139.15	3.00	140.54	4.25	0.0090
Added sugar (g)	25.86	0.27	27.09	0.36	24.71	0.66	22.25	0.70	21.20	1.05	<0.0001
Total fat (g)	89.17	0.38	89.42	0.48	89.96	0.95	88.21	1.26	85.97	1.71	0.0525
Saturated fatty acids (g)	29.58	0.16	29.82	0.20	30.08	0.41	29.00	0.52	26.63	0.69	<0.0001
Monounsaturated fatty acids (g)	33.65	0.16	33.80	0.21	34.30	0.41	33.05	0.53	31.37	0.72	0.0011
Polyunsaturated fatty acids (g)	18.12	0.13	17.93	0.16	17.76	0.29	18.52	0.42	20.56	0.64	<0.0001
Cholesterol (mg)	302.77	3.00	318.93	3.90	294.08	7.22	261.37	8.25	213.00	10.28	<0.0001
Micronutrient											
Vitamin A (retinol equivalents)	690.09	12.63	644.95	15.61	748.55	31.70	787.65	40.37	888.13	49.15	0.0000
Vitamin C (mg)	92.12	1.43	88.09	1.66	97.00	3.76	98.00	4.40	116.21	9.24	0.0021
Vitamin E (mg α-tocopherol)	7.94	0.09	7.58	0.09	8.21	0.19	9.18	0.48	9.21	0.39	<0.0001
Vitamin B-6 (mg)	1.93	0.01	1.81	0.02	2.12	0.04	2.20	0.06	2.27	0.10	<0.0001
Vitamin B-12 (μg)	5.34	0.11	5.25	0.15	5.62	0.25	5.85	0.32	4.68	0.28	0.9783
Folate (μg dietary folate equivalents)	411.15	3.07	380.72	3.05	467.18	9.11	482.54	12.47	490.82	18.80	<0.0001
Calcium (mg)	908.90	7.72	863.31	8.88	974.95	17.11	1045.61	34.89	1015.89	34.63	<0.0001
Magnesium (mg)	291.94	1.64	271.28	1.71	305.90	3.47	343.59	7.11	401.82	8.67	<0.0001
Potassium (mg)	2,779.40	14.09	2,733.68	17.55	2,835.11	35.04	2,881.73	43.68	2,982.19	73.68	<0.0001
Phosphorus (mg)	1,408.31	6.01	1,365.03	7.28	1,464.26	14.45	1,505.59	21.87	1,591.16	29.61	<0.0001
Iron (mg)	16.10	0.11	14.81	0.11	17.61	0.27	19.77	0.53	20.40	0.72	<0.0001
Sodium (mg)	3,702.82	19.01	3,680.43	23.73	3,800.92	51.49	3,718.55	59.11	3,687.14	83.84	0.4054

^aCovariates used were energy, sex, ethnicity, and age.

^bLSM=least square mean.

^cLSSE=least square standard error.

^dFor energy only, covariates used were sex, ethnicity, and age.

whole grains is associated with improved diet quality and nutrient intake. The number of servings of whole grains consumed was very low in both age groups examined. More than 70% of adults failed to consume the mean number of servings of whole grains. In adults aged 19 to 50 years, the percentage consuming three or more servings of whole grain was <5%. This intake is lower than several recent studies (4,11), but was similar to another study (41). This is likely the result of the change in the definition of whole grains or the database used.

A wide variety of reasons for consumers not choosing whole grains have been put forward, and include a lack of understanding of the health benefits, an inability to identify or purchase whole grains, an inability to incorporate whole grains into the family lifestyle, a lack of familiarity with preparation methods, the higher price of some whole-grain products, and the reported poor taste or texture (6,42-45). Evidence suggests that whole grains are less available in foodservice operations than in the home

(46). Because of these problems, it is important for health professionals, industry, government, and public health campaigns to promote the consumption of whole grains more vigorously (10). Registered dietitians should play a key role in the promotion of consumption of whole grains; however, some lack general knowledge about whole grains and ways to promote them (47,48). Health claims on Nutrition Facts panels are another way to help increase whole-grain consumption (46); however, consumers may be confused by nutrition labels and misunderstand the meaning (49,50). What is lacking is a national whole-grain campaign, such as the 5-A-Day campaign that promotes intake of fruit and vegetables (51,52).

In this study, it was found that consumption of whole grains was associated with energy intake. Other studies have also shown this (3,5,16,26). Most of these studies (3,16,26) showed that whole-grain consumption was also associated with decreased body mass index. Given that whole-grain foods are rich sources of dietary fiber, more

Table 3. Diet quality and adjusted^a nutrient intake of adults aged 51 y and older by whole-grain consumption group, according to data from the 1999-2004 National Health and Nutrition Examination Survey

Nutrient	No. of Servings										P for Trend
	Total Population		≥0 to <0.6		≥0.6 to <1.5		≥1.5 to <3.0		>3.0		
	n=6,237		n=4,372		n=691		n=761		n=413		
	LSM ^b	LSSE ^c	LSM	LSSE	LSM	LSSE	LSM	LSSE	LSM	LSSE	
Macronutrient											
Whole-grain servings	0.84	0.02	0.11	0.00	1.00	0.01	2.07	0.02	4.62	0.10	—
Healthy Eating Index	55.37	0.22	51.60	0.26	60.00	0.53	62.15	0.60	65.17	0.78	<0.0001
Energy ^d (kcal)	1,905.97	12.79	1,834.91	16.04	1,907.78	28.67	2,029.84	32.88	2,298.78	59.74	<0.0001
Protein (g)	73.75	0.37	73.40	0.53	75.46	0.84	73.59	0.95	73.17	1.43	0.9332
Carbohydrates (g)	232.63	0.99	223.98	1.39	238.08	2.06	247.51	2.62	268.56	3.77	<0.0001
Fiber (g)	15.73	0.14	13.31	0.15	17.07	0.28	19.90	0.38	26.22	0.75	<0.0001
Total sugar (g)	106.85	0.90	105.63	1.33	109.04	1.90	111.90	2.37	103.04	3.45	0.7390
Added sugar (g)	15.43	0.22	16.26	0.32	14.75	0.43	14.62	0.55	11.18	0.84	<0.0001
Total fat (g)	73.44	0.35	75.67	0.49	71.42	0.74	69.91	0.94	65.08	1.45	<0.0001
Saturated fatty acids (g)	23.51	0.14	24.45	0.19	22.50	0.28	22.04	0.40	20.21	0.64	<0.0001
Monounsaturated fatty acids (g)	27.22	0.15	28.18	0.21	26.50	0.33	25.68	0.40	23.30	0.58	<0.0001
Polyunsaturated fatty acids (g)	15.76	0.13	15.88	0.18	15.50	0.30	15.64	0.35	15.59	0.53	0.8213
Cholesterol (mg)	268.96	3.29	291.24	4.54	250.71	7.41	230.75	7.98	185.89	12.62	<0.0001
Micronutrient											
Vitamin A (retinol equivalents)	749.02	13.43	690.70	17.35	801.84	29.35	828.29	30.39	994.19	68.12	0.0000
Vitamin C (mg)	93.05	1.37	87.28	1.68	102.28	3.26	101.28	4.07	107.28	6.54	0.0003
Vitamin E (mg α-tocopherol)	7.45	0.09	7.04	0.10	7.65	0.21	8.64	0.40	8.31	0.42	<0.0001
Vitamin B-6 (mg)	1.77	0.01	1.61	0.02	1.94	0.03	2.06	0.05	2.24	0.09	<0.0001
Vitamin B-12 (μg)	5.01	0.12	4.71	0.14	5.95	0.51	5.29	0.23	4.88	0.34	0.1256
Folate (μg dietary folate equivalents)	376.74	3.00	345.89	3.24	416.12	7.13	431.34	10.31	455.66	16.85	<0.0001
Calcium (mg)	772.48	6.95	728.84	8.76	825.77	18.71	870.65	20.03	849.94	29.13	<0.0001
Magnesium (mg)	270.09	1.54	244.57	1.72	285.51	3.04	313.50	4.40	378.71	8.17	<0.0001
Potassium (mg)	2,702.30	14.09	2,606.96	18.21	2,825.41	31.04	2,860.17	42.03	2,963.55	63.74	<0.0001
Phosphorus (mg)	1,199.30	5.70	1,139.48	7.34	1,263.25	14.49	1,298.69	14.74	1,393.65	25.15	<0.0001
Iron (mg)	14.81	0.12	13.21	0.11	16.11	0.28	17.80	0.42	20.30	0.66	<0.0001
Sodium (mg)	3,083.46	18.00	3,098.55	24.40	3,067.82	43.98	3,034.79	46.15	3,078.13	64.54	0.6112

^aCovariates used were energy, sex, ethnicity, and age.

^bLSM=least square means.

^cLSSE=lease square standard error.

^dFor energy only, covariates used were sex, ethnicity, and age.

^aCovariates used were energy, sex, ethnicity, and age.

^bLSM=least square means.

^cLSSE=least square standard error.

^dFor energy only, covariates used were sex, ethnicity, and age.

studies are needed to separate out the protective effect of whole grains on body weight independent of fiber intake. Wang and colleagues (5) showed that there was no difference in body mass index across whole-grain consumption quintiles. What is not clear from these studies is whether the additional energy intake came from grains or from other food sources. In general, those consuming more whole grains had a healthier lifestyle (5,16,26), including increased physical activity, reduced smoking, and consumed other foods generally thought to be healthy. This was not shown by Newby and colleagues (3), so further study would provide additional information to help understand the relationship of energy intake, weight, and consumption of whole grains.

Consumption of whole grains improved diet quality as indicated by the HEI score (53) across the grain consumption groups. This was underscored by the improvement in intake in virtually all macro- and micronutrients examined, except vitamin B-12 and sodium. This was not un-

expected since vitamin B-12 is found in foods from animal sources and whole grains are low in sodium. The focus in this discussion will be on the majority of the shortfall nutrients in the diets of adults (fiber; vitamins A, C, and E; calcium; magnesium; and potassium), as identified by the Dietary Guidelines Advisory Committee (19). The shortfall nutrients are found naturally in whole grains (1,23). Whole grains are not a good source of vitamins A or C; however, intake of both these vitamins increased in both age groups with increased consumption of whole grains, suggesting that those individuals consuming more servings of whole grains may have an overall healthier diet than those consuming fewer servings. This was demonstrated in this study where adults who consumed the most servings of whole grains had better overall diet quality. More research is needed to examine whether individuals who consume whole grains also consume more of the other food groups, exercise more, and/or consume less added fats and added sugars.

Fiber intake is associated with improved weight status, serum cholesterol levels, blood pressure, blood sugar control, and laxation (54). The overwhelming majority of adults in the United States do not meet their fiber requirement (54,55). The DRI for men aged 19 to 50 years and 51+ years is 38 g/day and 30 g/day, respectively, and for women of those ages is 25 g/day and 21 g/day, respectively. As seen in this study, other studies have shown that increased whole grain consumption is associated with increased fiber intake (16,27). This study showed that on average those aged 19 to 50 years who consumed three or more servings of whole grains approached the fiber requirement and those aged 51 years and older met the fiber requirement (data from men and women assessed separately, but not shown separately).

Epidemiologic evidence suggests that vitamin E intake is associated with a reduced incidence of all cause and cause-specific mortality (56). Less than 10% of the population meets the Estimated Average Requirement for vitamin E from food alone (56). Vitamin E is found in whole grains; however, only 5% (11) to 21% (57) of vitamin E is retained as wheat is processed and it is not among the nutrients added in the enriching process. Although vitamin E intake was improved in the study participants with increased consumption of whole grains, the mean intake did not approach the DRI of 15 mg/day for adults. Koh-Banerjee and colleagues (58) also showed an increased intake of vitamin E with increased intake of whole grains; however, that study included dietary supplements in the nutrient analysis. Results from this study suggest that other sources of vitamin E, such as vegetable oils, nuts, leafy green vegetables, and fortified cereals should be added to a whole-grain-rich diet to help improve vitamin E intake.

Magnesium is an essential cofactor for more than 300 metabolic reactions; high intake is associated with an inverse risk of type 2 diabetes (59) and metabolic syndrome (60). The relationship between magnesium intake and development of cardiovascular risk factors and hypertension is less clear. Ford and Mokdad (61) showed in a nationally representative population of adults that most Americans do not meet the recommendations for magnesium intake. On average in this study, those consuming three or more servings of whole grain met the DRI for magnesium (350 mg/day).

Potassium is the most abundant intracellular cation and plays an important role in membrane transport, energy metabolism, fluid balance, and cell functioning; potassium derangements can cause deterioration in cardiac and neurological functioning. Dietary potassium is also inversely related to a risk of hypertension and stroke. Mean potassium intake in adults does not meet recommendations (62). This study showed that consumption of whole grains was associated with increased potassium intake; however, even at the highest intake of more than three servings per day, mean intake fell short of the recommendation of 4,700 mg/day (63) by approximately 1,700 mg/day. Other good sources of potassium, including dairy foods, fruit, and vegetables should be included in a whole-grain-rich diet.

Limitations

This study had several limitations. NHANES is a cross-sectional study; thus, causal inferences cannot be drawn. The results may not reflect current intake and changes in whole-grain consumption that may be a result of recent changes in food intake patterns, new food products, and contemporary diet trends. Participants relied on their memory to self-report dietary intakes and, therefore, data were subject to nonsampling errors, such as underreporting of energy and examiner effects. Further, 24-hour dietary recalls may not accurately reflect the usual dietary intake patterns of participants. Overall, however, the very large sample sizes, such as those available through NHANES, 24-hour recalls produce reasonably accurate group estimates of nutrient intake.

CONCLUSIONS

Overall consumption of whole grains in the population remains low using a recently updated definition; however, diet quality and nutrient profiles could be improved with greater consumption of whole grains. Whole-grain consumption should be encouraged by health professionals, especially registered dietitians. Nutrition education programs that increase awareness, health benefits, and consumption of whole grains should be designed. Future research needs include quantifying the effect that whole-grain consumption has on diet quality in children, and, assessing the effect that whole-grain consumption has on health status.

STATEMENT OF POTENTIAL CONFLICT OF INTEREST: No potential conflict of interest was reported by the authors.

FUNDING/SUPPORT: This work is a publication of the USDA/Agricultural Research Service (ARS) Children's Nutrition Research Center, Department of Pediatrics, Baylor College of Medicine, Houston, TX. The contents of this publication do not necessarily reflect the views or policies of the USDA, nor does mention of trade names, commercial products, or organizations imply endorsement from the US government. This research project is supported by the USDA/ARS through specific cooperative agreement 58-6250-6-003 and by Kellogg's Corporate Citizenship Fund. Partial support was received from the USDA Hatch Projects 940-36-3104 Project No. 93673 and LAB 93676 No. 0199070.

ACKNOWLEDGEMENTS: The authors thank Pamela Harris for help in preparing the manuscript.

References

1. Slavin J. Whole grains and human health. *Nutr Res Rev.* 2004;17:99-110.
2. Cleveland LE, Moshfegh AJ, Albertson AM, Goldman JD. Dietary intake of whole grains. *J Am Coll Nutr.* 2000;19(suppl 3):331S-338S.
3. Newby PK, Maras J, Bakun P, Muller D, Ferrucci L, Tucker KL. Intake of whole grains, refined grains, and cereal fiber measured with 7-d diet records and associations with risk factors for chronic disease. *Am J Clin Nutr.* 2007;86:1745-1753.
4. Lin B-W, Yen ST. *The U.S. Grain Consumption Landscape. Who Eats Grain, in What Form, Where, and How Much?* Hyattsville, MD: US Department of Agriculture, Economic Research Service; 2007. Report No. ERR-50.
5. Wang L, Gaziano JM, Liu S, Manson JE, Buring JE, Sesso HD. Whole- and refined-grain intakes and the risk of hypertension in women. *Am J Clin Nutr.* 2007;86:472-479.

6. Kantor LS, Variyam JN, Allshouse JE, Putnam JJ, Lin BH. Choose a variety of grains daily, especially whole grains: a challenge for consumers. *J Nutr*. 2001;131(suppl):473S-486S.
7. Whole grain definition. US Food and Drug Administration Web site. Updated February 24, 2006. <http://www.cfsan.fda.gov/~dms/fdsup130.html>. Accessed July 10, 2008.
8. American Association of Cereal Chemists. AACCC to create consumer-friendly definition of whole grains [press release]. March 5, 2004. <http://www.aaccnet.org/news/CFWholeGrain.asp>. Accessed July 11, 2008.
9. Franz M, Sampson L. Challenges in developing a whole grain database: Definitions, methods and quantification. *J Food Compos Anal*. 2006;19(suppl):S38-S44.
10. Jones JM, Reicks M, Adams J, Fulcher G, Weaver G, Kanter M, Marquart L. The importance of promoting a whole grain foods message. *J Am Coll Nutr*. 2002;2:293-297.
11. Steffen LM, Jacobs DR, Jr., Stevens J, Shahar E, Carithers T, Folsom AR. Associations of whole-grain, refined-grain, and fruit and vegetable consumption with risks of all-cause mortality and incident coronary artery disease and ischemic stroke: The Atherosclerosis Risk in Communities (ARIC) Study. *Am J Clin Nutr*. 2003;78:383-390.
12. Jensen MK, Koh-Banerjee P, Hu FB, Franz M, Sampson L, Gronbaek M, Rimm EB. Intakes of whole grains, bran, and germ and the risk of coronary heart disease in men. *Am J Clin Nutr*. 2004;80:1492-1499.
13. Liese AD, Roach AK, Sparks KC, Marquart L, D'Agostino RB Jr, Mayer-Davis EJ. Whole-grain intake and insulin sensitivity: The Insulin Resistance Atherosclerosis Study. *Am J Clin Nutr*. 2003;78:965-971.
14. de Munter JS, Hu FB, Spiegelman D, Franz M, van Dam RM. Whole grain, bran, and germ intake and risk of type 2 diabetes: A prospective cohort study and systematic review. *PLoS Med*. 2007;4:e261.
15. Katcher HI, Legro RS, Kunselman AR, Gillies PJ, Demers LM, Bagshaw DM, Kris-Etherton PM. The effects of a whole grain-enriched hypocaloric diet on cardiovascular disease risk factors in men and women with metabolic syndrome. *Am J Clin Nutr*. 2008;87:79-90.
16. Good CK, Holschuh N, Albertson AM, Eldridge AL. Whole grain consumption and body mass index in adult women: An analysis of NHANES 1999-2000 and the USDA pyramid servings database. *J Am Coll Nutr*. 2008;27:80-87.
17. Schatzkin A, Mouw T, Park Y, Subar AF, Kipnis V, Hollenbeck A, Leitzmann MF, Thompson FE. Dietary fiber and whole-grain consumption in relation to colorectal cancer in the NIH-AARP Diet and Health Study. *Am J Clin Nutr*. 2007;85:1353-1360.
18. Jacobs DR Jr, Steffen LM. Nutrients, foods, and dietary patterns as exposures in research: A framework for food synergy. *Am J Clin Nutr*. 2003;78(suppl 3):508S-513S.
19. Report of the Dietary Guidelines Advisory Committee on the Dietary Guidelines for Americans, 2005, to the Secretary of Health and Human Services and the Secretary of Agriculture. Washington, DC: The Dietary Guidelines Advisory Committee; 2004.
20. Liu S, Stampfer MJ, Hu FB, Giovannucci E, Rimm E, Manson JE, Hennekens CH, Willett WC. Whole-grain consumption and risk of coronary heart disease: Results from the Nurses' Health Study. *Am J Clin Nutr*. 1999;70:412-419.
21. US Department of Health and Human Services, Public Health Service, Office of Disease Prevention and Health. *Healthy People 2010: Volumes I and II*. Conference ed. Washington, DC: US Government Printing Office; Washington, DC; 2000.
22. Federal Food and Drug Administration's health claims for whole grain. Published December 9, 2003. <http://www.cfsan.fda.gov/~dms/flgrain2.html>. Accessed July 10, 2010.
23. Edge MS, Jones JM, Marquart L. A new life for whole grains. *J Am Diet Assoc*. 2005;105:1856-1860.
24. Friday JE, Bowman SA. MyPyramid Equivalents database for USDA survey food codes, 1994-2002, Version 1.0. US Department of Agriculture, Agricultural Research Service Web site. <http://www.ars.usda.gov/Services/docs.htm?docid=8498>. Accessed August 27, 2007.
25. Jacobs DR Jr, Meyer KA, Kushi LH, Folsom AR. Whole-grain intake may reduce the risk of ischemic heart disease death in postmenopausal women: The Iowa Women's Health Study. *Am J Clin Nutr*. 1998;68:248-257.
26. Jacobs DR Jr, Andersen LF, Blomhoff R. Whole-grain consumption is associated with a reduced risk of noncardiovascular, noncancer death attributed to inflammatory diseases in the Iowa Women's Health Study. *Am J Clin Nutr*. 2007;85:1606-1614.
27. Jensen MK, Koh-Banerjee P, Franz M, Sampson L, Gronbaek M, Rimm EB. Whole grains, bran, and germ in relation to homocysteine and markers of glycemic control, lipids, and inflammation. *Am J Clin Nutr*. 2006;83:275-283.
28. USDA Pyramid servings database. Last modified February 2, 2009. US Department of Agriculture, Agricultural Research Service Web site. <http://www.ars.usda.gov/Services/docs.htm?docid=8498>. Accessed March 28, 2009.
29. Bachman JL, Reedy J, Subar AF, Krebs-Smith SM. Sources of food group intakes among the US population, 2001-2002. *J Am Diet Assoc*. 2008;108:804-814.
30. Melanson KJ, Angelopoulos TJ, Nguyen VT, Martini M, Zukley L, Lowndes J, Dube TJ, Fiutem JJ, Yount BW, Rippe JM. Consumption of whole-grain cereals during weight loss: Effects on dietary quality, dietary fiber, magnesium, vitamin B-6, and obesity. *J Am Diet Assoc*. 2006;106:1380-1388.
31. NHANES Analytical Guidelines. Published June 2004. http://www.cdc.gov/nchs/data/nhanes/nhanes_general_guidelines_june_04.pdf. Accessed July 9, 2008.
32. Jonnalagadda SS, Mitchell DC, Smiciklas-Wright H, Meaker KB, Van Heel N, Karmally W, Ershow AG, Kris-Etherton PM. Accuracy of energy intake data estimated by a multiple-pass, 24-hour dietary recall technique. *J Am Diet Assoc*. 2000;100:303-308.
33. NHANES Dietary Interview Component. February 2003. National Health and Nutrition Examination Survey Web site. http://www.cdc.gov/nchs/data/nhanes/frequency/drxtot_doc.pdf. Accessed July 9, 2008.
34. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Vitamin A, Vitamin K, Arsenic, Boron, Chromium, Copper, Iodine, Iron, Manganese, Molybdenum, Nickel, Silicon, Vanadium, and Zinc*. Washington, DC: National Academies Press; 2001.
35. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Vitamin C, Vitamin E, Selenium, and Carotenoids*. Washington, DC: National Academies Press; 2000.
36. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Thiamin, Riboflavin, Niacin, Vitamin B6, Folate, Vitamin B12, Pantothenic Acid, Biotin, and Choline*. Washington, DC: National Academies Press; 1998.
37. *USDA Database of Vitamin A (mcg RAE) and Vitamin E (mg AT) for National Health and Nutrition Examination Survey 1999-2000*. Beltsville, MD: Agricultural Research Service, Food Surveys Research Group; 2006.
38. Cook AJ, Friday JE. Pyramid Servings Database for USDA Survey Food Codes, Version 2.0. US Department of Agriculture, Agricultural Research Service Web site. <http://www.ars.usda.gov/Services/docs.htm?docid=8634>. Accessed August 27, 2007.
39. Healthy Eating Index SAS template. Modified April 24, 2008. http://www.cnpp.usda.gov/Publications/HEI/HEI-2005/HEI2005_NHANES_0102_PopulationScore.txt. Accessed: July 9, 2008.
40. NHANES Analytic and Reporting Guidelines. Updated December 2005, corrected September 2006. http://www.cdc.gov/nchs/data/nhanes/nhanes_03_04/nhanes_analytic_guidelines_dec_2005.pdf. Accessed July 9, 2008.
41. Mellen PB, Liese AD, Toozee JA, Vitols MZ, Wagenknecht LE, Herrington DM. Whole-grain intake and carotid artery atherosclerosis in a multiethnic cohort: The Insulin Resistance Atherosclerosis Study. *Am J Clin Nutr*. 2007;85:1495-502.
42. Adams JF, Engstrom A. Helping consumers achieve recommended intakes of whole grain foods. *J Am Coll Nutr*. 2000;19(suppl 3):339S-344S.
43. Chase K, Reicks M, Smith C, Henry H, Reimer K. Use of the think-aloud method to identify factors influencing purchase of bread and cereals by low-income African American women and implications for whole-grain education. *J Am Diet Assoc*. 2003;103:501-504.
44. Croy M, Marquart L. Factors influencing whole grain intake by health club members. *Top Clin Nutr*. 2005;20:166-176.
45. Smith AT, Kuznesof S, Richardson DP, Seal CJ. Behavioural, attitudinal and dietary responses to the consumption of wholegrain foods. *Proc Nutr Soc*. 2003;62:455-467.
46. Marquart L, Wiemer KL, Jones JM, Jacob B. Whole grains health claims in the USA and other efforts to increase whole-grain consumption. *Proc Nutr Soc*. 2003;62:151-160.
47. Marquart L, Pham AT, Lautenschlager L, Croy M, Sobal J. Beliefs about whole-grain foods by food and nutrition professionals, health club members, and special supplemental nutrition program for women, infants, and children participants/State fair attendees. *J Am Diet Assoc*. 2006;106:1856-1860.
48. Chase K, Reicks M, Jones JM. Applying the theory of planned behavior to promotion of whole-grain foods by dietitians. *J Am Diet Assoc*. 2003;103:1639-1642.
49. Leathwood PD, Richardson DP, Strater P, Todd PM, van Trijp HC. Consumer understanding of nutrition and health claims: Sources of evidence. *Br J Nutr*. 2007;98:474-484.

50. Cowburn G, Stockley L. Consumer understanding and use of nutrition labelling: A systematic review. *Public Health Nutr.* 2005;8:21-28.
51. Ashfield-Watt PA. Fruits and vegetables, 5+ a day: Are we getting the message across? *Asia Pac J Clin Nutr.* 2006;15:245-252.
52. Van Duyn MA, Kristal AR, Dodd K, Campbell MK, Subar AF, Stables G, Nebeling L, Glanz K. Association of awareness, intrapersonal and interpersonal factors, and stage of dietary change with fruit and vegetable consumption: A national survey. *Am J Health Promot.* 2001;16:69-78.
53. Kennedy E. Putting the pyramid into action: The Healthy Eating Index and Food Quality Score. *Asia Pac J Clin Nutr.* 2008;17(suppl 1):70-74.
54. Marlett JA, McBurney MI, Slavin JL. Position of the American Dietetic Association: Health implications of dietary fiber. *J Am Diet Assoc.* 2002;102:993-1000.
55. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids (Macronutrients)*. Washington, DC: National Academies Press; 2005.
56. Traber MG, Frei B, Beckman JS. Vitamin E revisited: Do new data validate benefits for chronic disease prevention? *Curr Opin Lipidol.* 2008;19:30-38.
57. Truswell AS. Cereal grains and coronary heart disease. *Eur J Clin Nutr.* 2002;56:1-14.
58. Koh-Banerjee P, Franz M, Sampson L, Liu S, Jacobs DR, Jr., Spiegelman D, Willett W, Rimm E. Changes in whole-grain, bran, and cereal fiber consumption in relation to 8-y weight gain among men. *Am J Clin Nutr.* 2004;80:1237-1245.
59. Song Y, Manson JE, Buring JE, Liu S. Dietary magnesium intake in relation to plasma insulin levels and risk of type 2 diabetes in women. *Diabetes Care.* 2004;27:59-65.
60. McKeown NM, Jacques PF, Zhang XL, Juan W, Sahyoun NR. Dietary magnesium intake is related to metabolic syndrome in older Americans. *Eur J Nutr.* 2008;47:210-216.
61. Ford ES, Mokdad AH. Dietary magnesium intake in a national sample of US adults. *J Nutr.* 2003;133:2879-2882.
62. Nicklas TA, O'Neil CE, Fulgoni VL 3rd. The role of dairy in meeting the recommendations for shortfall nutrients in the American diet. *J Am Coll Nutr.* 2009;28(1 suppl):73S-81S.
63. Food and Nutrition Board, Institute of Medicine. *Dietary Reference Intakes for Water, Potassium, Sodium, Chloride, and Sulfate*. Washington, DC: National Academies Press; 2004.