Current Research

Resistant Starch Intakes in the United States

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ABSTRACT

Objective Dietary fiber represents a broad class of undigested carbohydrate components. The components vary in chemical and physical nature and in their physiological outcomes. Resistant starch is starch that escapes digestion in the small intestine and that may be fermented in the large intestine. The purpose of this study was to estimate consumption of resistant starch by the US population and to identify key sources of dietary resistant starch.

Design A database of resistant starch concentrations in foods was developed from the publicly available literature. These concentrations were linked to foods reported in 24-hour dietary recalls from participants in the 1999-2002 National Health and Nutrition Examination Surveys and estimates of resistant starch intakes were generated.

Subjects The study population included 18,305 nonbreastfeeding individuals in the United States.

Statistical analysis The dietary intake of resistant starch was determined for 10 US subpopulations defined by age, sex, and race/ethnicity. Three estimates of resistant starch intake were made for each person based on the minimum, mean, and maximum concentrations of resistant starch in the foods consumed.

Results Americans aged 1 year and older were estimated to consume approximately 4.9 g resistant starch per day based on mean resistant starch concentrations (range 2.8 to 7.9 g resistant starch per day). Breads, cooked cereals/pastas, and vegetables (other than legumes) contributed 21%, 19%, and 19% of total resistant starch intake, respectively, and were top sources of resistant starch.

Conclusions Findings from this study suggest that the estimated intake of resistant starch by Americans is approximately 3 to 8 g per person per day. These estimates of resistant starch intake provide a valuable reference for researchers and food and nutrition professionals and will allow for more accurate estimates of total intakes of carbohydrate compounds that escape digestion in the small intestine.

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Dietary fiber represents a broad class of undigested carbohydrate components. The components vary in chemical and physical nature, and in their physiological outcomes. Some of the better known components include cellulose and lignin. It is now widely known that some dietary starch escapes digestion in the small intestine, and upon reaching the large intestine also acts as a component of dietary fiber in the body. This starch could potentially be a major contributor of fermentable carbohydrate in the large intestine.

Starch exists as large glucose polymers localized in granules in plants, although processing and preparation can change some of the starch to nongranular forms. Starch polymers can either be straight chain (amylose) or branched chain (amylopectin), and both are a source of dietary carbohydrate and energy (1). The structure of starch polymers and granules influences its digestibility, so consequently not all starches are equally affected by digestive enzymes (2). The starch that is not digested is called resistant starch, and the recognized definition for resistant starch is "the sum of starch and products of starch degradation not absorbed in the small intestine of healthy individuals" (3).

Four main subtypes of resistant starch have been identified based on structure or source (4). Starch that is physically inaccessible to digestive enzymes is called resistant starch type 1 (RS1). RS1 is found in whole or partly milled grains and seeds so would be present in whole-grain foods. Starch that is resistant to digestion due to the nature of the starch granule is referred to as resistant starch type 2 (RS2); this type of resistant starch is found in raw potato, unripe banana, some legumes, and in high amylose starches such as starch obtained from high amylose corn. Resistant starch that forms from retrograded amylose and amylopectin during food processing is called resistant starch type 3 (RS3). This resistant starch form is found in cooked and cooled foods such as potatoes, bread, and cornflakes. The fourth type of resistant starch, resistant starch type 4 (RS4), is produced by chemical modification.

The physiologic effects of resistant starch have been studied during the past 30 years in animals and human beings and include health effects in the large intestine and systemic effects. Health benefits in the large intestine include enhanced fermentation and laxation; increased uptake of minerals such as calcium; changes in the microflora composition, including increased *Bifidobacteria* and reduced pathogen levels; and reduced symptoms of diarrhea (5). Systemic effects involve

Table 1. Effects of RS2[a] from high amylose corn on measures of colonic fermentation							
Reference no.	Subjects	Subject characteristics	Length of intervention	Intake (g/d)	Change in weight (%)	Change in pH	Change in butyrate concentration (%)
8	13 M[b], 10 F[c]	Hypertriglyceridemia	4 wks	20	−0.9	−0.22*	55*
9	12 M, 12 F	Healthy	2 wks	22	24.0*		45*
10	11 M, 9 F	Family history of colorectal cancer	3 wks	22	26.7	−0.18*	69*
11	12 M, 11 F	Colonic adenomas	4 wks[d]	28	20.6	−0.1	
12	24 M	Hyperinsulinemic	14 wks	30	9.5		
13	24 M	Healthy	4 wks	32	19.4	−0.1	16
14	8 M	Healthy	19 d	37	29.7*	−0.6*	
15	5 M, 6 F	Healthy	3 wks	39	42.8*	−0.6*	38*
16	7 M, 5 F	Healthy	4 wks	55	49.0*	−0.15	

[a]RS2 (resistant starch type 2) is starch resistant to digestion due to the nature of the starch granule.
[b]M=male.
[c]F=female.
[d]Parallel control study; all other studies were crossover trials.
*Statistically significant change at $P<0.05$.

plasma glucose and insulin, insulin sensitivity, and fatty acid oxidation (6).

Most early research on the health benefits of resistant starch focused on fermentation-related outcomes. Short-chain fatty acids, primarily acetate, propionate, and butyrate, are produced during resistant starch fermentation. They directly influence the large intestine environment, for example, by lowering intestinal pH, which inhibits the growth of pathogenic bacteria, increases the absorptive potential of minerals, and inhibits absorption of compounds with toxic or carcinogenic potential (7). Short-chain fatty acids also stimulate colonic blood flow, increase tone and nutrient flow, promote colonocyte proliferation, and reverse atrophy associated with low-fiber diets (7).

Consequences of resistant starch fermentation are well established in clinical studies, particularly for resistant starch from high-amylose corn, which is the most widely studied source of resistant starch. Currently there are insufficient studies to compare different types and sources of resistant starch, so it is prudent to assess consistent effects across similar sources of resistant starch. Results of nine clinical trials evaluating the effects of resistant starch from high amylose corn on measures of colonic fermentation are summarized in Table 1. Significantly increased fecal weight was found in four of the nine studies measuring this endpoint. Resistant starch doses used for fermentation-based studies are typically high, and minimum effective dose is typically not assessed. The median effective resistant starch dose for the fecal weight endpoint was 38 g, and the minimum effective dose used was 22 g. Fecal pH decreased significantly in four of the seven studies measuring this endpoint. Statistically significant increases in fecal butyrate concentrations were found in four of the five studies assessing this endpoint.

Limited studies have assessed clinical effects of other sources of resistant starch. For example, intakes of 17 to 30 g resistant starch from potato, banana, wheat, and corn resulted in significant increases in fecal weight and short-chain fatty acid excretion (17). Others have assessed the synergistic effects of resistant starch in combination with other sources of dietary fiber. Intake of 22 g/d RS2 from high amylose corn in combination with 12 g/day dietary fiber from unprocessed wheat bran increased fecal weight, decreased fecal pH, decreased fecal total phenols and ammonia concentrations, and increased fecal short-chain fatty acid concentration relative to the wheat-bran group (10).

Some short-chain fatty acids are absorbed across the intestinal mucosa with effects extending beyond the large intestine. Robertson and colleagues (18) reported increased insulin sensitivity in healthy subjects fed 30 g/day RS2 for 4 weeks, suggesting a link with nonesterified fatty acids. Higgins and colleagues (6) fed healthy subjects a single meal containing 2.5, 5, or 10 g RS2 per 2,000 kcal and noted increased meal and total fat oxidation suggesting inhibition of acetyl coenzyme-A derivation from carbohydrate relative to fat in the liver. The benefit was observed at 5 g but not 10 g resistant starch, suggesting a fermentation/excretion threshold, or possibly increased lipid excretion due to a resistant starch/lipid association. Emerging research in animals has linked resistant starch fermentation to satiety, with increased expression of genes coding for the satiety hormones PYY and GLP-1 when rat diets contain RS2. Increased concentrations of these hormones were also measured in plasma (19,20).

Not only does resistant starch benefit health via fermentation, but because the starch does not contribute directly to blood glucose, it also helps to lower blood glucose and insulin levels. Reductions in plasma glucose and insulin responses were seen following meal-based resistant starch intakes of 11.5 g resistant starch (12), whereas postprandial blood glucose and insulin responses in adults with untreated borderline diabetes were lower after eating a meal containing 6 g resistant starch (21). Postprandial insulin responses decreased slightly but significantly in hypertriglyceridemic patients following consumption of a meal containing 5.8 g resistant starch (8). Glucose and insulin effects are less apparent when available carbohydrate is matched between test and control diets; for example Higgins and colleagues (6) reported no effects when meals contained up to 10 g resistant starch.

Some hurdles exist in relating the results of clinical resistant starch studies to actual dietary intakes. Analytical methods used to determine fiber content for labeling purposes in the United States do not capture much of the resistant starch in foods (22). Resistant starch intakes are difficult to estimate due to a paucity of data on the resistant starch content in foods, methodological limitations, and variations in individual responses to resistant starch (23,24). Nonetheless, intakes in some countries have been estimated. Per capita intakes of resistant starch by Europeans and populations in selected European countries (25-27) as well as populations in Australia and New Zealand (28,29) have been estimated to range from approximately 3 to 9 g/day, whereas intakes in India have been estimated to be approximately 10 g/day (30). We are unaware of any estimates of intake of resistant starch by Americans.

The recommended intake of dietary fiber in the United States ranges from 19 to 38 g per day (31) for the population aged 1 year and older. Fewer than 5% of Americans aged 1 year and older consume this much fiber (32). Current analytical methods for fiber capture only a small proportion of resistant starch in foods (22). If resistant starch is considered, effective levels of dietary fiber intake will be closer to recommended dietary fiber intake levels. Given the large gap between consumed and recommended levels of fiber, however, fiber intakes are likely to still fall short of recommendations.

The purposes of this study were to develop a provisional database of resistant starch concentrations in foods consumed by Americans, to use the provisional database and nationwide food consumption data to estimate resistant starch intakes by Americans, and to identify top dietary sources of resistant starch.

METHODS

Resistant Starch Concentration Data

A literature search was conducted using PubMed and Agricola databases to identify the resistant starch content of foods. Abstracts for articles judged potentially useful were reviewed, and articles with abstracts indicating the inclusion of resistant starch data were obtained. Citations in articles were also reviewed and relevant articles were retrieved. We used two criteria to determine if specific resistant starch values should be entered into the provisional starch database: the method of resistant starch analysis, and the similarity of foods analyzed to foods consumed in the United States.

Early studies on resistant starch content of foods were performed by collecting and analyzing effluent from ileostomy patients fed foods of interest (33-35). Other investigators (36) analyzed excreta from colectomized rats to estimate resistant starch content of foods. In constructing the provisional resistant starch database, we included food concentration values obtained in human ileostomy studies, but used data from rat colectomy study models only when no other source of data was available for a particular food.

Most recent studies of resistant starch in food have been conducted using in vitro methods that attempt to mimic human digestive processes, to allow greater efficiency and standardization in resistant starch analysis than is possible using in vivo methods. We included data from studies in which resistant starch concentrations were determined based on whole food samples (rather than dietary fiber residues), using direct or indirect in vitro methods.

Most direct methods currently used for resistant starch analysis are modifications of a method developed by Berry (37), in which resistant starch is quantified as the starch remaining after samples have been incubated with enzymes to remove nonresistant starch. In Berry's original method, and in some modified versions of this method, samples were incubated at high temperatures (95°C to 100°C); later investigators incubated samples at 37°C to more accurately reflect the human digestive process and to prevent gelatinization of starch in the samples. In constructing the provisional resistant starch database, we considered data from studies using 37°C incubation to be appropriate for inclusion, but we included data from studies using high-temperature incubation only when no other source of data was found for a particular food.

Indirect resistant starch analysis was developed by Englyst and colleagues (38). In the original method and later modifications, resistant starch is quantified as the difference between total starch and readily digestible starch. Indirect resistant starch analysis has been correlated with resistant starch measured in ileal effluent (38), so we considered all resistant starch data generated using this technique to be appropriate for inclusion in the provisional starch database.

Resistant starch fractions naturally occurring in foods may be affected by treatment of food samples before analysis. Grinding and/or homogenization of foods can reduce RS1 by breaking down cell structures, gelatinization reduces RS2, and cooling of cooked foods can increase RS3. In many studies, food samples were ground and/or homogenized before analysis, possibly resulting in underestimation of RS1. To reduce the possibility of underestimating RS1, a number of studies substituted actual chewing of samples by human subjects or simulated chewing by mincing or gently grinding. Due to the overall scarcity of data on resistant starch contents of foods, we did not exclude data generated from analysis of dried, ground, or homogenized samples.

For each study, the mean resistant starch concentration reported for each food was entered directly into the provisional resistant starch database. For some studies, we calculated a mean resistant starch concentration from results reported for multiple samples of the same type of food; multiple samples may have represented different cultivars or cooking and cooling steps. All values were converted to an "as consumed" basis before entry in the provisional resistant starch database, and all values correspond to grams resistant starch per 100 g food. For each food included in the database, we calculated an overall mean resistant starch concentration from the individual study means. For foods with more than one source of resistant starch data, the minimum and maximum individual study means were identified. Resistant starch concentrations were calculated for a total of 155 unique foods

Table 2. Database of resistant starch (RS) concentrations in foods

Food	g RS per 100 g Food[a]			Method of RS analysis	Reference no.
	Mean	Minimum	Maximum		
Breads					
Bagels, plain	0.7			+[b]	39
Breadsticks, hard	2.3			++[c]	25
Brioche	1.7			++	40
Croissant	0.4			+	41
Croutons	1.4			+	39
English muffin	1.0			+	39
Foccacia	1.2			+	39
French bread/rolls	0.5			+	41
Italian bread	1.2	0.6	1.7	++	25, 42, 43
Italian bread, toasted	3.8			++	42
Multigrain bread	0.9			++	44
Naan	0.3			+	41
Oatmeal bread	1.2			+	39
Pita, wheat	1.3			++	44
Pita, white	1.9			++	44
Poori	0.6			++	45
Pizza dough, baked	2.8	2.7	2.8	++	25, 42
Pumpernickel bread	4.5			++	44
Rye bread, wholemeal	3.2			++	46
Sourdough bread	2.1			++	25
Sweet rolls, fruit, not iced	0.2			+	41
Wheat rolls	0.1			+	41
Wheat germ bread	0.1			+	41
White bread	1.2	0.1	4.4	++	5, 10, 33, 36, 38, 44, 46-49, 50-56
White bread, high fiber	0.9			++	44
White rolls, crusty	0.3			+	41
White rolls, soft	0.5			+	41
Whole-wheat bread	1.0	0.5	1.5	++	25, 38, 44, 46, 48
Whole-wheat rolls	0.4			+	41
Tortillas, corn	3.0	2.3	3.5	++	57-60
Tortillas, flour	0			+	39
Tortillas, wheat	0			+	41
Breakfast cereals, cooked					
Oats, cooked	0.2	0	0.4	++	46, 61, 62
Rice porridge, made from rice flour	0.4			++	47
Breakfast cereals, ready-to-eat					
All-Bran[d]	0.7	0.4	1.1	++	44, 46, 48, 51
Alpen[e]	0			++	40
Bran Buds[d]	0.6			++	48
Bran flakes	0.7			+	39
Corn cereal, puffed	1.4			+	39
Corn flakes	3.2	1.8	6.3	++	30, 33, 36, 38, 40, 44, 47, 48, 50, 51, 54, 62-70
Corn square cereal	1.3			+	39
Granola	0.1			+	39
Grapenut-type cereal	0.8			+	39
Muesli	3.3	2.3	4.3	++	5, 44
Oat bran	1.0			++	46
Oatmeal square cereal	0.6			+	39
Oats, toasted	1.2			+	39
Puffed rice	2.3			++	30
Puffed wheat	6.2			++	46
Rice cereal, flaked	0			+	39

(continued)

Table 2. Database of resistant starch (RS) concentrations in foods (continued)

Food	g RS per 100 g Food[a]			Method of RS analysis	Reference no.
	Mean	Minimum	Maximum		
Rice Krispies[d]	1.9	1	2.5	++	38, 46, 48
Rice square cereal	4.2			++	39
Shredded wheat cereal	1.2	0.8	1.6	++	46, 70
Smacks[d]	1.6			++	48
Special K[d]	1.6			++	40
Weetabix[e]	0.1	0	0.2	++	46, 70
Wheat square cereal	1.4			+	39
Whole-wheat cereal, flaked	1.0			+	39
Cakes/muffins/pies/waffles					
Bread pudding	0.8			+	71
Cake, white, layer (no frosting), homemade	1.8			++	36
Crumpets	0.3			+	41
Fruit cake	0.1			+	71
Muffins, plain, homemade	1.0			+	36
Pastry, choux	0.5			+	71
Pie shell, frozen, baked	0.5			+	39
Puff pastry shells, frozen, baked	0.4			+	39
Scones, fruit	0.1			+	41
Sponge cake	0.2			+	71
Waffles, multigrain, frozen, toasted	0.5			+	39
Waffles, plain, frozen, toasted	0.6			+	39
Chips/snacks					
Cheese puffs	0.2			+	39
Chips, corn, low-fat	0.7			+	39
Chips, multigrain	0.9			+	39
Chips, potato	3.5	2.9	4.5	++	46, 54, 72, 73
Corn puffs, extruded-fried	0			+	39
Corn snack, crisp	0.8			+	39
Popcorn cakes	0.3			+	39
Pretzels, regular	1.0			+	39
Rice cakes	0.2			+	39
Cookies/crackers					
Biscuits, chocolate	0.8			++	70
Biscuits, milk	1.7			++	40
Biscuits, oatmeal	0.9			++	46
Biscuits, semisweet	0.4			++	70
Biscuits, water	0.6			++	46
Cereal bar, fruit-filled	2.3			++	5
Cookies, ginger snaps	0.4			+	39
Cookies, oatmeal	0.2			+	39
Cookies, shortbread	2.6			++	25
Cookies, sugar	0.3			+	39
Cookies, vanilla wafers	0.2			+	39
Crackers, five-grain snack	0.5			+	39
Crackers, club	0.4			+	39
Crackers, crispbread (Ryvita)[f]	2.8	0.8	4.3	++	5, 25, 38, 46, 61
Crackers, melba rounds	1.5			+	39
Crackers, oyster	0.5			+	39
Crackers, rice crunch	0.4			+	39
Crackers, rusk toast	1.8			++	48
Crackers, saltine (original)	0.6			+	39
Crackers, shredded wheat	1.2			+	39
Crackers, wheat, thin	0.4			+	39
Graham crackers	0.3			+	39

(continued)

Table 2. Database of resistant starch (RS) concentrations in foods (continued)

Food	g RS per 100 g Food[a]			Method of RS analysis	Reference no.
	Mean	Minimum	Maximum		
Granola bar, oats and honey	0.2			+	39
Ice cream cones, plain	0.3			+	39
Ice cream cones, sugar	0.5			+	39
Bananas/plantains					
Bananas, raw	4.0	0.3	6.2	++	34, 48, 54, 62, 70, 74
Bananas, cooked	0.8			++	62
Plantain, cooked	3.5			++	30
Cooked cereals/pastas[g]					
Barley, pearled, cooked	2.4	1.1	4.2	++	38, 46, 50, 68
Buckwheat groats, cooked	1.8	1.1	2.6	++	46, 56, 75
Corn polenta, cooked	0.8			++	53
Millet, cooked	1.7			++	38
Noodles, chow mein	0.4			+	39
Noodles, egg (wheat), cooked	1.6			++	25
Noodles, rice, cooked	0.9			++	76
Oats, rolled, uncooked	11.3	7.8	14.8	++	62, 77
Pasta, wheat (macaroni/spaghetti), cooked	1.1	0.5	1.5	++	25, 38, 43, 44, 46-48, 53, 54, 61, 70
Pasta, whole-wheat, cooked	1.4			++	44
Rice, brown, cooked	1.7	0	3.7	++	44, 46, 53, 78
Rice, white, long grain or unspecified, cooked	1.2	0	3.7	++	25, 44, 46-48, 51, 53-54, 62, 68, 70, 76, 78
Rice, white, long grain, parboiled, cooked	1.3	1	1.6	++	46, 61, 76, 78
Legumes					
Beans, black/brown, cooked/canned	1.7	1.3	1.9	++	79-81
Beans, kidney, cooked/canned	2.0	1.5	2.6	++	44, 46, 65-67
Beans, mung, cooked	1.6	1.3	1.8	++	30, 82
Beans, pinto, cooked	1.9	1.8	2	++	46, 54
Beans, white, cooked/canned	4.2	1.8	8.3	++	38, 46, 47, 54, 70, 83
Beans in tomato sauce	1.2	0.9	1.5	++	46, 61
Chickpeas, cooked/canned	2.6	0.8	4.3	++	25, 30, 44, 46, 52-54, 62, 82, 84
Cowpeas, cooked	0.6			++	82
Lentils, cooked	3.4	1.6	9.1	++	25, 38, 44, 46, 47, 53-54, 70, 85
Peas, mature, cooked/canned	2.6	1.6	4	++	25, 46, 53, 55
Pea soup	1.9			++	61
Pigeon peas	1.0			++	30
Vegetables (other than legumes)					
Corn, sweet, cooked/canned	0.3			++	46
Lima beans, cooked/canned	1.2			++	46
Peas, cooked/canned	1.9	0.9	2.2	++	25, 36, 38, 46, 54, 70
Potato croquettes	1.3			++	73
Potato dumplings	1.6	1.2	1.9	++	25, 42
Potato pancakes	1.1			++	73
Potato salad	1.0			++	73
Potatoes, baked	1.0	0.8	1.4	++	25, 72-73
Potatoes, boiled	1.3	0.3	4.5	++	25, 35, 38, 44, 47, 48, 53, 54, 61, 62, 70, 72, 73, 86-88
Potatoes, canned	1.0			++	73
Potatoes, fried	2.8	1.3	5.5	++	48, 61, 72, 73
Potatoes, instant, prepared	0.4	0.2	0.8	++	38, 46, 61, 72, 73
Potatoes, slow cooked	0.3			++	73
Sweet potatoes, cooked	0.7	0.3	1.1	++	30, 46
Yam, cooked	1.5	0.8	2.1	++	30, 46

(continued)

Table 2. Database of resistant starch (RS) concentrations in foods (continued)

Food	g RS per 100 g Food[a] Mean	Minimum	Maximum	Method of RS analysis	Reference no.
Miscellaneous					
Lasagna[h]	0.1			++	68
Meat loaf[i]	0.1			++	68
Pasta, egg, filled with cheese and tomato, cooked[h]	0.3			+	89
Pasta, egg, filled with cheese only, cooked[h]	0.3			+	89
Pasta, egg, filled with green veg/herbs and cheese, cooked[h]	0.6			+	89
Pasta, egg, filled with meat, cooked[h]	0.9			+	89
Pasta, egg, filled with mushrooms, cooked[h]	0.3			+	89
Tapioca, cooked	0.3			++	30

[a]Average RS values from each study were used to calculate mean, minimum, and maximum values in the database. Values of 0 indicate that no RS was found in the food sample.
[b]Indicates that RS values were derived from in vitro studies that do not necessarily mimic human digestion (eg, the food sample was boiled during analysis of RS).
[c]Indicates that RS values were derived from in vivo and/or in vitro studies that best mimic human digestion.
[d]Kellogg's, Battle Creek, MI.
[e]Weetabix Ltd, Kettering, Northamptonshire, UK.
[f]Ryvita Co, Birmingham, UK.
[g]Cooked cereals other than cooked breakfast cereals.
[h]RS source assumed to be pasta.
[i]RS source assumed to be bread.

or ingredients based on data derived from 60 publications (Table 2). The resistant starch values for 88 of the 155 foods or ingredients in the database were derived from in vivo and/or in vitro studies that best mimic human digestion. In general, the analytical precision of resistant starch measurements increases as resistant starch concentrations increase (48,66). The ranges of resistant starch concentrations per 100 g food in the provisional resistant starch database are shown by food group in Table 2.

Food Consumption Data Source

Data from the US Department of Health and Human Service's 1999-2000 and 2001-2002 National Health and Nutrition Examination Surveys (NHANES) were combined to create the study population. These surveys are part of a series of surveys conducted by the National Center for Health Statistics, Division of Health Examination Statistics, in the Centers for Disease Control and Prevention, and are designed to provide nationally representative nutrition and health data and prevalence estimates for nutrition and health status measures (90,91). The NHANES survey design is a stratified, multistage probability sample of the civilian noninstitutionalized US population.

As part of the examination component of the survey, trained dietary interviewers collect detailed information on all foods and beverages consumed by respondents in the previous 24-hour time period (midnight to midnight) using computerized, multipass collection methods. Dietary recalls from a total of 18,305 individuals (excluding breastfeeding children) were determined by the National Center for Health Statistics to be reliable and meet minimum criteria. Estimates of resistant starch intake were calculated based on the 5,096 unique food codes reported by these individuals in their dietary recalls.

Calculation of Resistant Starch In Foods Reported in NHANES 1999-2002

In mapping resistant starch concentration data to NHANES food codes, we assumed that there is no resistant starch in dairy products, meats/poultry/fish, fats/oils, or fruits and vegetables other than those listed in Table 2, as foods or as ingredients.

Data from the resistant starch database were mapped directly to NHANES identifiers for foods such as cooked pasta, bread and brand-name breakfast cereals. US Department of Agriculture data files were used to translate each food code into the percentage weight of each ingredient containing resistant starch in a food mixture (92,93). The weight of each ingredient was multiplied by the corresponding resistant starch concentration and the total resistant starch concentration per 100 g food was calculated by summing the resistant starch contributions from each ingredient. Average, minimum, and maximum resistant starch concentrations were calculated for each of the food codes (grams resistant starch per 100 g food).

We imputed resistant starch values for several NHANES foods or food ingredients thought to contain resistant starch, but for which we had no analytical resistant starch data. For example, resistant starch concentrations in flour-thickened sauces were imputed based on the resistant starch concentration in cooked pasta, adjusted for total starch content. A total of 2,631 of the 5,096 foods reported by survey respondents had nonzero resistant starch values based on mean resistant starch concentrations in our database.

Statistical Analysis

Three estimates of resistant starch intake were made for each person based on the minimum, mean, and maximum concentrations of resistant starch in the foods consumed. Estimates of mean resistant starch intakes by the entire US population aged 1 year and older and nine subpopulations of Americans were generated. For each of these 10 population groups, we also estimated intake by respondents identified as non-Hispanic white, non-Hispanic black, or Mexican American. The sample sizes for other race/ethnicity groups are too small to produce reliable estimates of intake. In cases where only one resistant starch value was found, the same value was assigned to the mean, minimum and maximum resistant starch concentration values.

Mean daily intakes of resistant starch from each of the nine major food categories (shown in Table 2) were estimated for respondents aged 1 year and older based on average resistant starch concentrations in each food. The percent contributions from each food category to total daily resistant starch intakes were based on the average resistant starch concentration data. All estimates were generated using survey sample weights to adjust for differences in representation of subpopulations; results therefore are representative of the US population.

RESULTS

The database of resistant starch concentrations in foods is presented in Table 2. As shown in Table 2, the estimated concentration of resistant starch varies greatly within some food categories. The variability in resistant starch concentrations in foods is likely due to a variety of factors, including natural differences (eg, based on cultivar), differences in food preparation methods, and differences in analytical methods.

Estimates of resistant starch intake by the US population and subpopulations are presented in Table 3. Americans aged 1 year and older were estimated to consume approximately 4.9 g resistant starch per day based on mean resistant starch concentrations; the calculated range of resistant starch intakes for this population is 2.8 to 7.9 g per day. Resistant starch intakes were highest for men aged 20 to 49 years, who consumed a mean of 5.9 g resistant starch per day (range 3.4 to 9.8 g).

Table 4 presents estimates of resistant starch intake by non-Hispanic white, non-Hispanic black, and Mexican American subpopulations. Estimates of resistant starch intake by non-Hispanic whites and non-Hispanic blacks aged 1 year and older are 4.6 (range 2.7 to 7.4) and 4.7 (range 2.6 to 7.8) g per day, respectively, whereas the estimated mean resistant starch intake by Mexican Americans aged 1 year and older is 5.3 g per day (range 3.2 to 8.2).

Results of the analysis of percent contributions to total resistant starch intake by food groups for Americans aged 1 year and older are shown in Table 5. These rankings reflect both the concentration of resistant starch in foods and the frequency of consumption of each food. Breads, cooked cereals/pastas, and vegetables (other than legumes) contributed 21%, 19%, and 19% of total resistant starch intake, respectively. Bananas/plantains provided 14% of resistant starch intake and legumes accounted for approximately 9% of daily intake. The remaining food sources included in this analysis each provided 1% to 7% of total resistant starch intake. The percent contributions to total starch intake by food source among non-Hispanic whites were similar to the pattern seen in the total population, although cooked cereals/pastas were the third largest source in this population compared to the second largest source in the total population. Food sources of resistant starch among non-Hispanic blacks also were similar to patterns in the general population, though cooked cereals/pastas were the top source of resistant starch among this race/ethnicity group and breads ranked third. Breads, accounting for approximately 27% of total resistant starch intake by Mexican Americans, were the top source of resistant starch for this population. The second largest source of resistant starch among Mexican Americans was legumes (16%), followed closely by bananas/plantains, vegetables (other than legumes), and cooked cereals/pastas, with each category accounting for 14 to 15% of total resistant starch intake.

Table 3. Resistant starch (RS) intakes by Americans, based on data from the National Health and Nutrition Examination Surveys, 1999-2002

		RS (g/d)	
Age group	**n[a]**	**Average[b]**	**Range[c]**
Infants and children[d]			
<1 y	706	1.9	1.0-3.2
1-5 y	2,013	3.7	2.0-6.0
6-11 y	2,098	4.2	2.6-6.8
Male			
12-19 y	2,244	5.5	3.5-9.0
20-49 y	2,128	5.9	3.4-9.8
≥50 y	2,101	5.6	2.9-9.3
Female			
12-19 y	2,261	4.3	2.6-6.9
20-49 y	2,622	4.4	2.6-7.1
≥50 y	2,132	4.2	2.1-6.9
All individuals ≥1 y[d]	17,599	4.9	2.8-7.9

[a]Unweighted sample size.
[b]Based on mean RS concentrations in foods.
[c]Based on minimum and maximum RS concentrations in foods.
[d]Excluding breastfeeding infants and children.

DISCUSSION

Findings from this study indicate that Americans aged 1 year and older consume approximately 5 g resistant starch per day. Intakes of resistant starch by Americans may range from less than 3 g to nearly 8 g based on the variability of resistant starch concentrations in the foods included in our provisional resistant starch database.

Table 4. Resistant starch (RS) intakes in the United States, by race/ethnicity, based on data from the National Health and Nutrition Examination Surveys, 1999-2002

	RS Intake (g/d)								
	Non-Hispanic White			Non-Hispanic Black			Mexican American		
Age group	n[a]	Average[b]	Range[c]	n	Average	Range	n	Average	Range
Infants and children[d]									
<1 y	219	2.0	1.0-3.1	151	1.9	0.9-3.3	263	1.8	0.8-3.0
1-5 y	633	3.3	1.9-5.3	521	4.1	2.2-6.7	646	4.0	2.1-6.4
6-11 y	572	3.9	2.5-6.1	682	4.5	2.8-7.4	705	4.9	2.9-7.6
Male									
12-19 y	580	5.4	3.5-8.4	672	5.3	3.5-8.5	830	5.4	3.5-8.3
20-49 y	921	5.7	3.4-9.2	445	5.8	3.3-9.9	586	6.5	4.0-9.8
≥50 y	1,196	5.3	2.8-8.7	356	4.8	2.4-8.3	413	5.9	3.2-9.2
Female									
12-19 y	576	4.0	2.5-6.3	661	4.1	2.6-6.8	842	4.4	2.8-7.1
20-49 y	1,142	4.1	2.5-6.5	531	4.3	2.4-7.1	701	5.2	3.1-8.0
≥50 y	1,157	4.1	2.1-6.5	373	3.7	1.9-6.2	443	4.3	2.3-6.8
All individuals[d] ≥1 y	6,777	4.6	2.7-7.4	4,241	4.7	2.6-7.8	5,166	5.3	3.2-8.2

[a]Unweighted sample size.
[b]Based on mean RS concentrations in foods.
[c]Based on minimum and maximum RS concentrations in foods.
[d]Excluding breastfeeding infants and children.

Table 5. Food sources of resistant starch (RS) intakes by Americans aged 1 year and older, based on data from the National Health and Nutrition Examination Surveys, 1999-2002

	Total Population[a]		Non-Hispanic White		Non-Hispanic Black		Mexican American	
Food Group	Rank	% of total RS	Rank	% of total RS	Rank	% of total RS	Rank	% of total RS
Breads	1	20.7	1	21.7	3	17.7	1	26.6
Cooked cereals/pastas	2	18.9	3	16.1	1	24.0	5	14.0
Vegetables (other than legumes)	3	18.9	2	20.6	2	19.3	4	14.7
Bananas/plantains	4	14.0	4	14.3	4	11.7	3	15.2
Legumes	5	9.2	5	7.6	5	8.3	2	16.4
Cakes/muffins/pies/waffles	6	6.8	6	7.5	6	7.8	6	4.6
Chips/snacks	7	4.5	7	5.0	7	5.1	8	3.5
Breakfast cereals, ready-to-eat	8	3.9	8	4.3	8	3.8	7	3.7
Cookies/crackers	9	1.6	9	1.9	9	1.4	9	0.9
Miscellaneous	10	1.4	10	1.0	10	0.9	10	0.4

[a]Excluding breastfeeding infants and children.

Overall our results are consistent with the range of resistant starch intakes generated by other investigators for other countries. In Australia, mean intakes of resistant starch for the population ranged from 3.4 to 9.4 g/day using the minimum and maximum concentrations, respectively, in 50 starchy foods (28). Top contributors to resistant starch intakes based on maximum resistant starch concentrations were potatoes and bananas, whereas bananas and white bread were the major contributors to daily resistant starch intakes when minimum concentrations were used.

Resistant starch intake by Europeans in 1993-1994 was estimated to be 4.1 g per day, with estimates of intake in the 10 individual countries ranging from 3.2 to 5.7 g per day (26). The estimates were developed from resistant starch concentration data developed for the study or published data for food groups including breads, potatoes, biscuits, breakfast cereals, pasta, rice, banana, rusk, and vegetables, although not all countries included data for all categories of foods.

Intakes of as little as 6 to 12 g resistant starch at a meal have been observed to have beneficial effects on postprandial glucose and insulin levels (12,21), whereas resistant starch intakes of approximately 20 g/day have been considered necessary to promote benefits in digestive health (eg, fecal bulking) (29). Based on our research, it appears that daily intakes of resistant starch by Americans are at or slightly below the lower end of the range of intakes associated with beneficial effects at a single meal, and considerably lower than daily intakes associated with health benefits. Americans could potentially realize more of the health effects associated with resistant starch by selecting more resistant starch-rich foods in place of foods with little or no resistant starch. Alternatively, commercial products made with added resistant starch could help consumers get levels of the starch that may deliver beneficial effects (5).

Our provisional resistant starch concentration database was developed based on a limited amount of publicly available data, and we had to make many assumptions in estimating resistant starch concentrations in foods reported to be consumed in NHANES. We included data generated using in vivo methods or in vitro methods that best mimic human digestive processes, and data generated using other methods were included only when no other data for a particular food were available. In addition, although we attempted to limit our provisional database to foods most similar to foods consumed by Americans, nearly all of the concentration data identified in our searches were generated on foods outside of the United States. Some foods such as ready-to-eat breakfast cereals were identified by brand name, and it was assumed that the resistant starch concentrations in these products are representative of the same brand cereals available in the United States. The composition and texture of some of the breads included in the database may be different than breads consumed in the United States. In addition, resistant starch values for some cereals, legumes, and other vegetables were based on analysis of cultivars not available in the US food supply. Consequently, the values in our database may not be entirely representative of foods consumed in the United States.

Despite these limitations in our provisional database, we believe our estimates of resistant starch intakes by Americans provide a valuable reference for intake of this potentially important dietary constituent. One of the major strengths of our study is the comprehensive search for and subsequent identification of resistant starch concentration data. Our database includes resistant starch concentrations for 155 different foods or food forms. These data provide not only more representative ranges of the natural variability of resistant starch within a select type of food, but also cover a greater number of foods than most studies of resistant starch intakes have used. We also generated estimates of mean resistant starch intakes and provided a range of intakes based on the variability of values in our database. The intakes based on minimum and maximum values are driven largely by the small number of foods for which multiple resistant starch concentrations were identified, but nonetheless define potential ranges of intake. In addition, the estimates were based on food consumption data from a nationally representative sample of the US population.

CONCLUSIONS

The estimated intake of resistant starch by Americans is in the range of approximately 3 to 8 g per person per day. These estimates of resistant starch intake provide a valuable reference for researchers and food and nutrition professionals. By combining estimates of resistant starch intake with those of other components of dietary fiber, researchers and food and nutrition professionals will be able to more accurately estimate total intakes of carbohydrate compounds that escape digestion in the small intestine and provide nutrients and function to the large intestine. As additional data on the resistant starch content of foods in the US food supply are generated, estimates of resistant starch intake can be refined.

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