

Problems and Methods in Applying Nutrient
Composition Data to Current Health Issues:
Dietary Fiber

by

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Dietary fiber consists of the plant material which is resistant to hydrolysis by the enzymes of the mammalian digestive tract. The publication of Burkitt and Trowell's epidemiological associations between lack of fiber in the diet and chronic diseases prevalent in Western and developed countries stimulated the interest of clinicians, nutritionists, and gastroenterologists in fiber as an important component of foods. Because of the complexity of dietary fiber, the etiology by which it may affect disease remains uncertain; however, evidence has been accumulating that fiber supplements or fiber-rich foods can modulate the digestive and absorptive process and may have benefit as therapeutic agents. Given the increasing emphasis placed on the importance of fiber in the diet, we have been faced with the problem of trying to accurately determine the fiber content of foods and particularly to determine the components of fiber which may be important in the gastrointestinal tract. In my presentation I plan to cover some of the methods that have been developed to determine the fiber content of foods. To illustrate some of the problems and complexities in determining dietary fiber, it is necessary first of all to consider some of the diversity in the chemical and physical properties of dietary fiber and to discuss the variations in physiological effects which have been associated with sources of fiber.

Fiber as a group are found in plant materials. The most abundant compounds associated with fiber are associated with the plant cell wall. Some of the compounds identified as fiber are part of the intracellular cement in plants, others are secreted by the plant in response to injury, or are used to prevent seeds from desiccating. Because of these functions the general group dietary fiber can be divided into 3 sections: Structural Polysaccharides, which include those polysaccharide that are associated with the cell wall and include cellulose and the noncellulose polysaccharides (hemicelluloses and some pectins); Structural Nonpolysaccharide of which lignins are the main category; and the Nonstructural Polysaccharides, which include the gums and mucilages which are secreted by cells and the polysaccharides such as carrageenan and agar from algae and seaweed. Table 1 gives the average distribution of the cellulose, noncellulosic polysaccharide, and lignin fractions found in cereal, vegetables, and fruits. In all of these the noncellulose polysaccharides are likely to be present in a greater proportion than cellulose or lignin, and fruits and vegetables tend to be higher in cellulose than cereals. Some of the fruits have a very high proportion of lignin, which is likely to occur if seeds are a part of the edible portion of the fruit, as with strawberries. When examining the distribution of fiber in plants, it is important to keep in mind that the fibrous composition will vary by the species of plant, part of the plant (e.g. root vs. leaf), and the maturity of the plant. For example, the

lignin content generally increases significantly as the plant matures.

Just as their functions in the plants vary, the chemical composition of each fraction varies widely. Table 2 describes the chemical components found in various fiber. The simplest is cellulose which is a glucose polymer without branching. The noncellulose polysaccharides are based on a variety of carbohydrates and can contain a high degree of branching. Lignin is a highly complex nonpolysaccharide polymer which contains phenylpropane units. The structures of the major polysaccharide components of fiber are shown in figure 1. Cellulose is a linear polymer of glucose with beta 1-4 links, it is the main structural component of plant cell walls, and it is considered relatively insoluble. D-galacturonic acids are the major component of pectins. The carboxyl groups on the galacturonic acids are partially methylated which are important to the properties of pectic substances. Pectins can have various carbohydrates linked to it. They are generally considered as highly soluble and are found as part of the cell wall and as intercellular cement. Hemicelluloses are a heterogenous group; the component sugars which make up its backbone and side chains are shown in figure 1. Hemicelluloses as a group are soluble in dilute alkali; however, there is a wide range in solubility with a greater solubility being associated with a high degree of branching. The structure of a purified lignin is highly complex and has a three dimensional structure. Lignins are considered very inert, insoluble, and resistant to digestion.

The description above provides a brief overview of the chemical diversity of dietary fiber. Sources of fiber also have unique physical properties which are clearly important in determining the physiological response to fibers. Table 3 summarizes some of those physical properties and indicates the type of compound for which that physical property may be important in eliciting a physiological response. Although dietary fibers cannot be degraded by the enzymes in the mammalian small intestine, they can be fermented by the bacteria in the large bowel. The polysaccharides and not lignin are the compounds degradable by bacteria. Among the polysaccharides, there is considerable variations in the degree of degradation. For example, pectins, mucilages, and hemicelluloses appear to be completely degraded by bacteria whereas cellulose is only partially broken down. The physical structure within the plant will also determine the extent of breakdown, hence fiber from fruits and vegetables appear to be more fermentable than that from cereals and grains. The extent of bacterial breakdown of fibers is important for several reasons. During the breakdown short chain fatty acids are produced which may be important metabolically, the fermentation process can lower the pH which could be important for microbial metabolism, and bacterial cells can account for a significant portion of the fecal weight hence their growth can contribute to fecal bulk.

The second physical property of importance associated with dietary fibers is their water-holding capacity. The presence of sugar residues with free polar groups in polysaccharides is associated with a significant hydration capacity. Hydration of the fibers results in formation of a gel matrix, which can also result in a higher viscosity of the small intestinal contents. The pectins and mucilages and, to a limited extent hemicelluloses, have the greatest water-holding capacity. Within the small intestine water holding capacity may have an important effect on nutrient absorption. Presumably diffusion of nutrients for absorption will be slowed by partitioning of water-soluble nutrients into the gel matrix and because of increases in the viscosity of the intestinal contents. Water-holding capacity has also been associated with increased fecal bulk;

however, the relationship is not straightforward because of the degradation of fiber by bacteria in the colon.

The third physical property of interest with dietary fiber is the ability to bind organic molecules. Molecules of interest include bile acids, cholesterol, and toxic compounds. In vitro studies have demonstrated that lignin is a potent bile acid adsorbent. Pectin and other acidic polysaccharides also seem to sequester bile acids. In contrast cellulose has little bile acid binding ability. In vivo bile acid adsorption is primarily measured as the ability to increase fecal bile acid steroid excretion. The ability to increase fecal excretion has been associated with the plasma cholesterol lowering effect of certain soluble, noncellulose polysaccharides, such as pectin and guar gum. The potential ability of some fibers to bind toxic compounds has been proposed as a mechanism for fibers to protect against gastrointestinal cancers; however, this property has not been studied extensively.

The fourth physical property concerns the cation exchange properties of certain fibers. The lower mineral availability and electrolyte absorption associated with diets high in fiber is undoubtedly due to the ability of some sources of fiber to bind minerals and electrolytes and increase their fecal excretion. The number of free carboxyl groups on the sugar residues and the uronic acid content of polysaccharides appears to be related to the cation exchange properties of fibers. These are 4 of the physical properties of fibers which are important in explaining the physiological response to fiber in the diet and it is evident that there is considerable diversity in these properties which is related to the diversity in chemical composition of dietary fibers.

Some of the physiological effects of dietary fibers include increased fecal bulk, decreased nutrient availability, lowering of plasma cholesterol, and reduction in the glycemic response to a meal. For each of these effects there are examples of fibers which are effective and those which are not. Two examples, fecal bulk and plasma cholesterol response, are useful to illustrate this point. The data in Table 4 were obtained from several studies which reported the percentage increase in fecal bulk with various fiber supplements. Coarsely ground wheat bran is the most effective in for increasing fecal bulk (80-120% increase). Disrupting the physical structure of wheat bran eliminates its effectiveness as a bulking agent, probably because it no longer holds water or because it is more readily degraded by bacteria. This is an example where it is not sufficient to know the absolute amount of fiber consumed but also know the physical form of the fiber. It is also possible to contrast different sources of fiber. The data indicate that the soluble, noncellulose polysaccharides tend not to be effective as fecal bulking agents. In the case of pectin and gums such as guar, the lack of bulking effect is because they are degraded by bacteria in the large bowel. The other example is shown in table 5 in which the ability of several fiber sources to lower plasma cholesterol is shown. The sources of noncellulose polysaccharide which are viscous appear to be most effective in lowering plasma cholesterol. These are also the fiber sources which are most effective in blunting the plasma glucose response. This suggests that the ability to form a gel matrix may be important in mediating the physiological response to these fiber sources. The importance of viscosity for lowering the postprandial glycemic response has been demonstrate in several studies. Hence that physical property must be maintained for the fibers to be effective.

It is clear that the term dietary fiber is used to encompass a very diverse group which of course becomes a tremendous problem for the analysis of the fiber content of foods. The methods for determining fiber include three basic approaches. One has been to use extraction methods to isolate various fractions and quantify gravimetrically. Extraction with acid and alkali is the basis of the crude fiber analysis, which has been the current AOAC method. The crude fiber procedure does not measure any specific carbohydrate or group of carbohydrates and consequently it does not accurately estimate the dietary fiber content nor does it have a quantitative relationship to fiber content of foods. The other extraction method is based on neutral and acid detergent extraction to isolate fractions. This method was originally developed by Van Soest for analysis of animal forages, and has had to be modified for analysis of human foods which are high in fat, protein, or starch. It has the advantage of being relatively rapid and useful for estimating the insoluble structural polysaccharides and lignin. A modified NDF is an official method of the American Association of Cereal Chemists. The second approach to determining the fiber content of food has been to analyze the individual components in the fiber residue. The best known of these procedures has been the Southgate procedure which involves a series of extraction steps to remove individual fractions, followed by hydrolysis and determination of the component sugars by gas-liquid or liquid chromatography. Other investigators have proposed extraction and chromatographic schemes to analyze the fiber content of foods in this way. This approach is difficult and time-consuming; however, in view of the variability in physiological response to different sources of fiber there is clearly a need for the detailed analytical data provided by these methods. In addition, analysis by this more rigorous and accurate method is needed to provide reference values to evaluate the results of simpler procedures. The third approach has been the development of rapid enzymatic procedures to provide a single value for the soluble and insoluble fiber content of the food. Enzymes are used to remove protein and starch from fat-extracted food. The residue is corrected for ash and protein content and the fiber determined gravimetrically. AOAC currently has this method under review. The enzymatic procedure supplies the need for a rapid gravimetric procedure but does not replace the need for a more comprehensive method to determine individual fiber components. Table 6 presents some of the results from the interlaboratory study to evaluate the enzymatic fiber method. For most of the samples the coefficient of variation is between 5 and 25 % and the lower CV tended to be associated with the higher level of fiber. This range of variability is in agreement with the variability reported by other fiber methods. For 2 of the samples the CV were unacceptably high (64 and 100 %). In the case of rice, incomplete digestion of the starch may have caused problems and in the case of soy protein isolate, the protein content may not have been determined and reported accurately by some laboratories. The method was also compared to the method of Englyst (nonstarch polysaccharides) and of Theander and Aman (component analysis). The methods appeared to give good agreement for the total dietary fiber content of the foods.

Table 7 contains a chart to provide a relative comparison among methods for the determination for the fiber content of foods. The Southgate or component analysis procedure was not included; however, the method was designed to determine each component which it does. The main problem encountered has been that incomplete removal of starch can interfere with the analyses. If we compare the 4 methods most commonly used we can see the relative value of each for fiber estimation. The crude fiber method detects cellulose and lignin;

however, they are not estimated accurately nor are the noncellulose polysaccharides estimated. This method seriously underestimates the fiber content of food and is not related in any systematic way to the dietary fiber content of foods. The neutral detergent method primarily estimates the structural components of the cell wall hence it does not provide values on the soluble fiber sources which must be estimated by other methods. The procedure by itself underestimates the total fiber content of a food, but in conjunction with an analysis of soluble polysaccharides such as pectins or gums is useful. The acid detergent fraction mainly contains the lignin and cellulose components with perhaps some small amounts of hemicellulose and pectin. Originally it was thought that the difference between NDF and ADF would provide the hemicellulose content but that has not proved to be an accurate method. Both of these methods then will underestimate the fiber content primarily because of the loss of soluble fibers. The final method is the enzymatic procedure in which all of these fractions will be part of the total fiber estimation. This procedure is most likely a slight overestimation of fiber content because of potential contributions from starch or heated proteins.

At the present time we are hampered in providing nutrient information by not having accurate, complete information on the fiber content of food. It is clear that the values for crude fiber are of little use in trying to evaluate dietary fiber intake and the association between fiber intake and disease patterns. If the enzymatic method reaches the final stages of approval, we will at least have a more accurate means to report total fiber content. There are many applications in which this information will be useful such as for labeling and for evaluating trends in dietary consumption. At present, individuals who are interested in some of the therapeutic uses for fiber will need more accurate information on the components of various fiber sources.

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Composition of Dietary Fiber Sources

	Noncellulose Polysaccharides %	Cellulose %	Lignin %
Cereals, 8 samples			
Average	75.7	17.4	6.7
Range	71-82	12-22	Tr-15
Raw Vegetables, 11 samples			
Average	65.6	31.5	2.98
Range	52-76	23-42	Tr-13
Fruits, 10 samples			
Average	62.9	19.7	17.4
Range	46-78	9-33	1-38

Southgate, 1978

Dietary Fiber Estimation by Enzymatic Analysis

	Dietary Fiber, %		Reproducibility
	Average	Std. Dev.	(cv), %
Corn bran	89.02	2.63	2.95
Wheat bran	82.25	2.23	5.29
Lettuce, freeze-dried	23.31	2.75	11.79
Whole wheat flour	12.92	1.43	11.04
Oats, quick-cooking	12.47	3.20	25.64
Lacto-ovo vegetarian mix	8.59	1.90	22.07
Soya isolate	7.51	7.58	100.93
Potatoes, instant	7.22	0.96	13.24
Nonvegetarian mix	7.19	1.90	26.39
Rye bread, dried	5.90	1.45	24.41
Raisins, seedless	4.43	1.03	23.12
Rice, powdered	3.67	2.35	64.15
White wheat flour	3.07	1.01	39.95

Prosky et al., 1984; Analysis by 30-32 laboratories.

Chemical Classification of Dietary Fiber

Fiber	Chemical Components	
	Main Chain	Side Chain
Polysaccharides		
Cellulose	Glucose	None
Noncellulose Hemicellulose	Xylose Mannose Galactose Glucose	Arabinose Galactose Glucuronic acid
Pectic substances	Galacturonic acid	Rhamnose Arabinose Xylose Fucose
Mucilages	Galactose-mannose Glucose-mannose Arabinose-xylose Galacturonic acid-rhamnose	Galactose
Gums	Galactose Glucuronic acid-mannose Galacturonic acid-rhamnose	Xylose Fucose Galactose
Algal polysaccharides	Mannose Xylose Guluronic acid Glucose	Galactose
Lignin	Sinapyl alcohol Coniferyl alcohol p-Coumaryl alcohol	3-dimensional structure

Fecal Bulk Associated with Fiber Supplements

Fiber Source	% Increase in fecal wet weight
Oat bran	15
Pectin	16-35
Guar gum	20
Apple	40
Carrot	59
Cabbage	67
Cellulose	75
Wheat bran, coarse	80-127
Wheat bran, fine	24

Ref: Jenkins et al., 1979; Kirby et al., 1981; Kay and Truswell, 1977; Miettinen and Tarpiu, 1977; Wrick et al., 1983.

Physicochemical Properties of Fibers in the Gut

Property	Type of Fiber	Result
1. Bacterial Degradation	Polysaccharides	Short chain fatty acids Flatulence, Chemical environment.
2. Water-holding Capacity	Polysaccharides with polar groups	Nutrient absorption. Fecal weight, transit in stomach and small intestine.
3. Adsorption of organic materials	Lignin Pectin	Bile acid binding and excretion.
4. Cation exchange	Acidic polysaccharides	Increase mineral excretion.

Change in Serum Cholesterol with Plant Fiber Supplements

Source of Fiber	Plant fiber g/day	Cholesterol % change
Cellulose	16	0
Wheat bran	17	+1
Whole oats	15	+11
Oat bran	27	+17
Pectin	25	+13
Guar gum	24	+16
Bengal gram	unknown	+22
Beans	30	+19

Anderson and Chen, 1983

ANALYSIS OF FIBER IN FOODS

	Cellulose	Hemicelluloses	Lignin	Pectin	Total Fiber Content
Crude Fiber	+++	+	--	0	underestimates
Neutral Detergent Fiber (NDF)	++++	---	----	0	underestimates soluble fibers
Acid Detergent Fiber (ADF)	++++	+	----	+	underestimates
Enzymatic Procedure	✓	✓	✓	✓	slight over-estimation

Key: + indicate degree to which compound is determined
0 not estimated
✓ part of total fiber estimation

NUTRIENT INTERACTION ISSUES

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This presentation covers nutrient interactions, and the impact of these interactions, on nutrient bioavailability. Nutrient bioavailability includes two important components, absorption and utilization (1). Absorption is the process by which a nutrient moves from the intestinal lumen into the body. Until nutrients are absorbed, they are still outside of the body and are not available to perform their functions. Utilization of the absorbed nutrients includes transport to various parts of the body, assimilation by cells, and conversion to biologically active forms.

The major effects of nutrient interactions on bioavailability and thus nutrient requirements, can be illustrated with zinc and iron. Daily endogenous losses of these minerals has been estimated at 2.2 mg of zinc, 1 mg of iron for men and postmenopausal women, and 1.5 mg of iron for women during their reproductive years. If zinc absorption were 40%, only 5.5 mg of dietary zinc per day would replace body losses, but if absorption were only 10%, 22 mg per day would be needed in the diet. One mg of zinc in the first diet would be equivalent to 4 mg in the second. Women would need about 6.5 mg of iron in a highly available (23% absorbed) form, but they would need 50 mg a day if the iron were in a poorly available form (3% absorbed). One mg of highly available iron would be equivalent to 6 mg of a poorly available form. The higher levels of both minerals are considered nearly impossible to obtain routinely in a diet without supplements. Thus, nutrient interactions which affect bioavailability adversely can impair nutritional status. Some of the examples of nutrient interactions I will discuss have been known for some time and are relatively well understood. However, most are newer research observations. The mechanisms of these interactions and their implications are not yet well understood.

Interactions can affect all of the major categories of nutrients; protein, carbohydrates, fats, vitamins, and minerals. Nutrients in each of these categories can also affect bioavailability of other nutrients. Interactions of nutrients with non-nutrient components of foods can alter availability. The effects of dietary fiber were discussed in the previous presentation. Other examples of non-nutrients which interact with nutrients include oxalate, avidin, and phytate. Oxalate combines with calcium to form an insoluble salt. The avidin in raw egg white renders biotin unabsorbable.

High levels of phytate have been known for some time to impair zinc availability in rats. However, the effect of phytate on zinc absorption in humans had not been confirmed until recently. In a study conducted in a human metabolic unit, young men consumed diets with no phytate or diets with sodium phytate added (2). Zinc absorption was determined with ^{67}Zn , a stable isotope of zinc. The results are shown in the table below.