DIETARY FIBER

1. Introduction

Historically, dietary fiber referred to insoluble plant cell wall material, primarily polysaccharides, not digested by the endogenous enzymes of the human digestive tract. This definition has been extended to include other nondigestible polysaccharides, from plants and other sources, that are incorporated into processed foods. Cellulose [9004-34-6] is fibrous; however, lignin [9005-53-2] and many other polysaccharides in food do not have fiberlike structures.

Cell-wall dietary fiber is a complex system composed of variable amounts of cellulose, other polysaccharides such as hemicellulose [9034-32-6] and pectin [9000-69-5], and lignin. The precise composition and proportion of polysaccharide types is related to the plant source, stage of maturity, and growing conditions. The composition and physical properties of dietary fiber also may be affected by both postharvest physiological changes and food processing. Cereal grains, legumes, vegetables, and fruits are primary sources of dietary fiber. A smaller proportion of total dietary fiber comes from polysaccharides (gums and mucilages) added for their functionality in processed foods.

The variation in water solubility among polysaccharides results in varied physiological roles. Plant cell-wall polysaccharides and lignin provide insoluble dietary fiber (IDF); nondigestible storage polysaccharides, some pectic polysaccharides, and most of the functional additives contribute soluble dietary fiber (SDF).

Interest in dietary fiber has been stimulated by epidemiological evidence of differences in colonic disease patterns between cultures with diets containing large quantities of fiber, and Western cultures having more highly refined diets. Many African countries, for example, are relatively free of diverticular disease, ulcerative colitis, hemorrhoids, polyps, and cancer of the colon (1). Whereas most interest has focused on the beneficial role of dietary fiber, there is also concern that high fiber diets may cause disturbances in the absorption of nutrients such as minerals and vitamins. Some studies claim this is a misconception and that the food's phytate content is mainly responsible for bioavailability of certain minerals and vitamins (2). The interrelationships between consumption of dietary fiber and health status have been obscured by inadequate knowledge of the quantity and structural chemistry of dietary fiber in various food sources and the physiological roles of the fiber components.

Still there is continuous emphasis on the importance of dietary fibers. One challenge to the industry is to produce products with a lower calorie count without sacrificing organoleptic appeal of the core product. As future research details specific nutritional benefits of individual components of dietary fiber, food companies will need flexible alternatives in order to validate new functional food claims and to respond rapidly to emerging trends in fiber-enriched products. These objectives will be achieved by understanding the physiochemical basis for the biotechnical functionality of fibers and by developing and making available fibers that provide a broad spectrum of bioactive and texture modulating properties (3).

2. Terminology

Various names have been proposed for the nondigestible part of plant cells, names suggesting either the fibrous nature of some of the cell-wall polysaccharides or their resistance to digestive tract enzymes. Fiber values in food composition tables originally were based on crude fiber analyses, but this assay does not give a true picture of even the fibrous cell-wall material. The term crude fiber is not equivalent to dietary fiber and has little practical meaning. Likewise, the terms unavailable (or nonavailable) carbohydrate and nonnutritive fiber fail to recognize the presence of lignin in fiber or the microbial fermentation of polysaccharides that occurs in the colon. The term nonstarch polysaccharides (NSP) emphasizes the nondigestible character of fiber and is supported by appropriate analytical methodology, but excludes lignin.

Other names have been proposed based on specific methods of analysis. In the Van Soest detergent methods (4), the terms *neutral detergent fiber* (NDF) or *neutral detergent residue* (NDR), and *acid detergent fiber* (ADF) refer to the insoluble hemicellulose–cellulose–lignin complex and to the cellulose–lignin complex of the plant cell wall, respectively. Before the importance of soluble dietary fiber was recognized, NDF was accepted as a measure of dietary fiber even though it reflects insoluble fiber only.

Dietary fiber is the accepted terminology in the United States for nutritional labeling. Total dietary fiber (TDF) and its subfractions, insoluble dietary fiber (IDF) and soluble dietary fiber (SDF), are defined analytically by official methods (5,6).

3. Sources, Composition, and Structure of Dietary Fiber

Natural sources of fiber in the diet include fruits, vegetables, legumes, and cereal grain products. The insoluble fiber content of some processed foods and breads is supplemented by incorporation of purified cellulose, cereal brans, or other plant fiber preparations. Cellulose and its chemically modified derivatives; seaweed polysaccharides, alginates [9005-32-7] and carrageenans [9000-07-1]; seed mucilaginous polysaccharides, guar and locust bean galactomannans [11078-30-1]; highly complex plant exudate polysaccharides, gum arabic [9000-01-5], tragacanth [9000-65-1], and others; microbially synthesized polysaccharides, xanthan [11138-66-2] and gellan gum [71010-52-1]; pectins; and other plant polysaccharides are added to foods for a variety of purposes. Because these materials are also nondigestible, they contribute to the total effect of dietary fiber and are encompassed by its definition.

Dietary fiber is a mixture of simple and complex polysaccharides and lignin. In intact plant tissue these components are organized into a complex matrix, which is not completely understood. The physical and chemical interactions that sustain this matrix affect its physicochemical properties and probably its physiological effects. Several of the polysaccharides classified as soluble fiber are soluble only after they have been extracted under fairly rigorous conditions.

Lignin, a highly polymerized alkylaromatic substance, is associated with the decreased digestibility by colonic microbial enzymes of some cell-wall

polysaccharides. Lignification also renders the structural polysaccharides less soluble and extractable. The degree of lignification is specific to plant type and increases with plant maturity as the lignin infiltrates the primary and secondary cell walls. Edible plant material has a relatively low content of lignin.

There is a great diversity of chemical structures in the polysaccharides of plant tissue. Table 1 lists some principal types of polysaccharides in edible land plants using simplified structures. Other reviews (7–9) provide a more complete description of the complex structures. Complete structures for many of the polysaccharides of edible sources have not yet been determined.

Any starch (qv) escaping digestion in the upper gastrointestinal tract also contributes to dietary fiber effects. Some food starches, and the amylose fraction in particular, are readily converted into a nondigestible or slowly digestible physical form under certain food processing conditions. These resistant starches are readily fermented by colonic bacteria. Small amounts of waxes, cutin, and minerals in fruits and vegetables contribute to total dietary fiber values but may be physiologically inert.

4. Physiological Properties

The beneficial effects of dietary fiber, including both soluble and insoluble fiber, are generally recognized. Current recommendations are for daily intakes of 20–35 g in a balanced diet of cereal products, fruits, vegetables, and legumes, but the average American's daily intake is only 12–18 g. However, the specific preventive role of dietary fiber in certain diseases has been difficult to establish, in part because dietary risk factors such as high saturated fat and high protein levels are reduced as fiber levels increase.

The role of dietary fiber in the prevention of cardiovascular disease has received increasing attention as data have accumulated. Recent cohort studies have found a consistent protective effect of dietary fiber on cardiovascular disease outcomes. The biologic mechanisms of how this works have yet to be fully elucidated. Recent research in a large national sample in the United States has demonstrated an association between dietary fiber and levels of C-reactive protein, a clinical indicator of inflammation (10).

Dietary fiber is important in the functioning of the entire gastrointestinal (GI) tract and affects the structure and morphology of the intestine. The process of chewing insoluble fiber-rich foods increases salivation and the flow of gastric secretions. Fiber components that increase viscosity or gel, for example, guar gum and pectin, delay gastric emptying. Fibers exert buffering action and may alter gastric pH by their effect on gastrointestinal hormones. A reduced glycemic response, probably resulting from delayed absorption of glucose, is associated with various fiber fractions, particularly viscosity-enhancing fibers.

Dietary fiber has a pronounced effect on the characteristics of the fecal mass and on the rate of passage of digest through the GI tract. The particle size and shape, density, and water-holding capacity (WHC) of dietary fiber influence the flow rates. Because hydratability and WHC are determined by chemical structure, crystallinity, overall plant tissue morphology, and lignin content,

food processing, such as grinding and heat processing, indirectly affects the rate of passage. Insoluble fiber in the diet increases the rate of passage, frequency of defecation, and the fecal mass, although there are large variations among individuals.

High fiber diets also play a role in the excretion of bile acids and cholesterol [57-88-5]. Insoluble fiber, particularly lignin, promotes excretion of bile acids and salts. Viscous soluble fiber components, such as pectin, guar, and soluble (1→3),(1→4)-β-D-glucan [55965-23-6], are associated with a lowering of serum cholesterol and triglycerides in hyperlipemic individuals by an unclear mechanism. There has been concern that high fiber diets might impair absorption of minerals and some vitamins, but healthy adults on a balanced diet should not be affected. Epidemiological studies show a negative correlation between colon cancer and high fiber diets, however, a definitive protective role in humans has not been established experimentally.

Dietary fiber is degraded extensively in the colon by bacterial action, yielding short-chain fatty acids, primarily acetic acid [64-19-7], propionic acid [79-09-4], and butyric acid [107-92-6], and gases, such as hydrogen, carbon dioxide, and methane. Because the human digestive enzymes known to hydrolyze polysaccharides are amylases, that is, (1→4)-α-D-glucanases [9000-90-2], acting in the upper GI tract, dietary fiber was assumed to pass into the colon largely unchanged. However, studies of ileostomy patients have provided evidence that not all of the dietary hemicelluloses are passed from the small intestine into the colon intact, suggesting that some bacterial activity also occurs in the lower small intestine. Colonic bacteria possess inducible enzymes that actively degrade and ferment much of the fiber polysaccharides as well as the mucosal polysaccharides from the host (11). Some individuals possess bacteria with cellulolytic activity, but hemicelluloses and soluble polysaccharides are more actively fermented.

Fiber components are the principal energy source for colonic bacteria with a further contribution from digestive tract mucosal polysaccharides. Rate of fermentation varies with the chemical nature of the fiber components. Short-chain fatty acids generated by bacterial action are partially absorbed through the colon wall and provide a supplementary energy source to the host. Therefore, dietary fiber is partially caloric. The short-chain fatty acids also promote reabsorption of sodium and water from the colon and stimulate colonic blood flow and pancreatic secretions. Butyrate has added health benefits. Butyric acid is the preferred energy source for the colonocytes and has been shown to promote normal colonic epithelial cell differentiation. Butyric acid may inhibit colonic polyps and tumors. The relationships of intestinal microflora to health and disease have been reviewed (12).

5. Physicochemical Properties

Several physicochemical properties of dietary fiber contribute to its physiological role. Water-holding capacity, ion-exchange capacity, solution viscosity, density, and molecular interactions are characteristics determined by the chemical structure of the component polysaccharides, their crystallinity, and surface area.

5.1. Water-Holding Capacity (WHC). All polysaccharides are hydrophilic and hydrogen bond to variable amounts of water. Hydratability is a function of the three-dimensional structure of the polymer (13) and is influenced by other components in the solvent. Fibrous polymers and porous fiber preparations also absorb water by entrapment. The more highly crystalline fiber components are more difficult to hydrate and have less tendency to swell. Structural features and other factors, including grinding, that decrease crystallinity or alter structure, may increase hydration capacity and solubility. However, fine grinding of insoluble dietary fiber such as bran reduces WHC. In general, branched polysaccharides are more soluble than are linear polysaccharides because close packing of molecular chains is precluded. WHC is strongly influenced by the pentosan components of cell-wall dietary fiber and varies with the structure and source of these hemicelluloses.

Soluble polysaccharides, such as agar [9002-18-0] and pectin, which form three-dimensional networks stabilized by physical or covalent interactions imbibe large quantities of water to form rigid gels (13). The gelling behavior and high viscosity of both the single-unit branched polysaccharides, such as the galactomannans, and the cereal (1→3), (1→4)-β-D-glucans affect GI tract function. The moderation of blood glucose levels observed with diets containing the viscous soluble polysaccharides may be related to a decrease in intraluminal mixing and a consequent decrease in the rate of absorption of glucose.

5.2. Ion Exchange. Acidic polysaccharides containing uronic acids, sulfate, or phosphate groups are cation exchangers, binding metal ions. The type of cation bound to these groups influences the physical properties of the polysaccharide. For example, alginic acid [9005-32-7], which is relatively insoluble as the free acid, is soluble as the sodium salt and forms a gel, calcium alginate [9005-35-0], with calcium ion. The cation-exchange capacity of dietary fiber is primarily dependent on the pectic acid content and glucuronic acid-containing hemicelluloses. Ion-exchange capacities have been determined for several dietary fiber sources (14), and the evidence suggests that cooking may alter the exchange capacity.

5.3. Molecular Interactions. Various polysaccharides readily associate with other substances, including bile acids and cholesterol, proteins, small organic molecules, inorganic salts, and ions. Anionic polysaccharides form salts and chelate complexes with cations; some neutral polysaccharides form complexes with inorganic salts; and some interactions are structure specific. Starch amylose and the linear branches of amylopectin form inclusion complexes with several classes of polar molecules, including fatty acids, glycerides, alcohols, esters, ketones, and iodine/iodide. The absorbed molecule occupies the cavity of the amylose helix, which has the capacity to expand somewhat to accommodate larger molecules. The starch–lipid complex is important in food systems. Whether similar inclusion complexes can form with any of the dietary fiber components is not known.

Soluble polysaccharides interact indirectly with proteins by competing for water and decreasing the solubility of the protein. Structure-specific interactions are exemplified by the lectins. These proteins interact with carbohydrates having a specific structure; the consequence of such interactions is aggregation and precipitation of the insoluble complex. This interaction displays the characteristics of an antigen–antibody reaction because it is characterized by a strict structural

requirement for both carbohydrate and protein, competitive inhibition by the monomer sugar, a reversible reaction, and dissolution of the complex at high carbohydrate concentrations. If such interactions occur in the gastrointestinal tract, the nutritional availability of the protein can be impaired.

Dietary fiber and fiber-rich food fractions bind bile acids and bile salts *in vitro*. This interaction is more pronounced for the lignin component.

6. Analysis of Dietary Fiber

Analytical methods suitable for routine assays measure groups of fiber components having similar solubility properties. Values may be expressed as *total dietary fiber (TDF)*, *insoluble dietary fiber (IDF)*, or *soluble dietary fiber (SDF)*. Quantitative analysis of specific fiber components other than cellulose, (1→3), (1→4)-β-D-glucans, (1→4)-α-D-galacturonans, and lignin is time-consuming because it involves fractionation of complex, chemically similar polysaccharides. The more commonly used fiber analysis methods are detergent methods for cell-wall fiber, enzymatic gravimetric methods for soluble and insoluble polysaccharides, and methods that include a quantitative analysis of the component sugars in the fiber fractions. The method selected defines IDF and SDF, since solubility of polysaccharides is affected by temperature and pH.

6.1. Detergent Methods. The *neutral detergent fiber (NDF)* and *acid detergent fiber (ADF)* methods (4), later modified for human foods (15), measure total insoluble plant cell wall material (NDF) and the cellulose–lignin complex (ADF). The easily solubilized pectins and some associated polysaccharides, galactomannans of legume seeds, various plant gums, and seaweed polysaccharides are extracted away from the NDF. They cannot be recovered easily from the extract, and therefore the soluble fiber fraction is lost.

The detergent method for insoluble fiber superseded the crude fiber method and became the method of choice for insoluble fiber analysis until the 1980s, when methods were developed to recover soluble fiber as well. Some analysts still prefer the NDF procedure for insoluble fiber. The method is simple, inexpensive, reproducible, and amenable to routine assays. The disadvantage is the inability to recover the soluble fraction. See Reference 16 for more information on detergent methods.

Neutral Detergent Fiber (AACC Method 32-20). The ground sample is extracted for 1 h under reflux at pH 7.0 with a buffered detergent solution containing sodium lauryl sulfate [151-21-3] and ethylenediaminetetraacetic acid [60-00-4]. Protein, soluble polysaccharides, and low molecular-weight substances are dissolved. Starch in high concentration interferes and is removed by α-amylase [9000-90-2] digestion. Although pancreatic α-amylase was used in the original modified NDF method (15), the heat stable α-amylase is more convenient (16). The insoluble fiber residue is collected by filtration, dried, and corrected for ash to give the NDF value. Certain products containing highly viscous water-soluble gums may be difficult to analyze because of retarded filtration, but in general the method is convenient and reliable for insoluble fiber.

Acid Detergent Fiber. The ground sample is heated for 1 h under reflux in a solution of 2% cetyltrimethylammonium bromide [57-09-0] in 1 *N* sulfuric acid

[7664-93-9]. The acid hydrolyzes and dissolves the noncellulosic polysaccharides. The insoluble residue, relatively free of hemicelluloses and containing all the cellulose and lignin, is filtered, dried, and corrected for ash to give the ADF value.

Cellulose may be extracted from the ADF with 72% sulfuric acid (w/w) at 4°C for 24 h leaving an insoluble residue of lignin. The loss in mass of the ADF estimates the cellulose component. Alternatively, cellulose may be estimated by hydrolysis of the ADF and determination of glucose.

In some processed foods insoluble artifacts generated during heat processing remain in the ADF residue together with the true lignin. The permanganate method for lignin gives a correct value. Ligninlike artifacts are not measured by this lignin procedure.

6.2. Enzymatic Gravimetric Methods for TDF, SDF, and IDF. These methods use an α-amylase and protease to remove starch and reduce protein. They differ from each other in the conditions for gelatinization of starch. Elimination of detergent permits recovery of soluble fiber, which is not possible with the detergent methods.

AOAC Method 985.29 for TDF. This AOAC method (5), referred to as the method of Prosky and co-workers (6), was cited in the Nutritional Labeling and Education Act of 1990 as the general analytical approach for food labeling of dietary fiber content. The method has undergone several modifications for TDF and for the primary fractions, SDF and IDF.

The dry milled food sample is digested sequentually with heat-stable α-amylase in phosphate buffer at 95–100°C and then at 60°C with protease and amyloglucosidase [9032-08-0] to remove protein and starch. The soluble fiber is precipitated with ethanol, and the combined soluble and insoluble fiber is collected by filtration, dried, weighed, and corrected for residual protein and ash to give a value for TDF. This method has also received AOAC official first action for IDF. For this value the insoluble residue from the amyloglucosidase digestion is collected by filtration, dried, weighed, and corrected for protein and ash. Although SDF can be obtained from the supernatant by precipitation with ethenol, the accuracy is not acceptable for some products.

AACC Method 32-07 for TDF, SDF, and IDF. This approved method is a modification of the Prosky method. The phosphate buffer is replaced by a buffer of 2(*N*-morpholino)ethanesulfonic acid (MES) [4432-31-9] and tris(hydroxymethyl)aminomethane (TRIS) [77-86-1]. Precision is improved and analysis time is reduced. TDF may be determined on a separate sample or calculated by summing the SDF and IDF values. The MES/TRIS-modified method has received final approval by AACC and official first action by AOAC (5).

AACC 32-06 Rapid Dietary Fiber Method for TDF, SDF, and IDF. The dietary fiber is determined by separate assays for soluble and insoluble fiber using a modification of AOAC 985.29 for SDF and the pancreatic α-amylase/NDF procedure for IDF. The SDF and IDF values are added to give TDF. Determination of the SDF requires autoclaving at 120°C for starch gelatinization, a more rigorous treatment than in the other enzymatic gravimetric methods. Corrections for protein are not required. TDF values are generally comparable to those obtained by the other methods described and affords a considerable time savings (17). The procedure, with minor modifications, has been submitted for final approval by AACC.

Urea Enzymatic Dialysis Method. This method (18) uses 8 *M* urea [57-13-6] to gelatinize and facilitate removal of starch and promote extraction of the soluble fiber at mild (50°C) temperatures. Following digestion with heat-stable α-amylase and protease, IDF is isolated by filtration or TDF is obtained after ethanol precipitation. Values for TDF are comparable to those obtained by the methods described earlier, and this method is less time-consuming than are the two AOAC-approved methods. Corrections for protein are required as in the AOAC methods.

6.3. Methods Based on Constituent Sugar Analysis. Unlike the gravimetric methods, these methods (19,20) arrive at dietary fiber values (TDF, SDF, IDF) by chromatographic (glc or hplc) analysis of the constituent sugars after extraction and fractionation of the fiber. Uronic acids, determined by decarboxylation or colorimetric analysis, and lignin values are taken into account in the calculation of the fiber values to give values comparable to those obtained by the gravimetric methods. If the lignin value is not included in the calculation, then a value for nonstarch polysaccharides (NSP) (20) is obtained. These methods are more time-consuming but give additional information about the component polysaccharides in the fiber. Because of the heterogeneity of plant polysaccharides, it is virtually impossible to give precise quantitative information on the individual polysaccharides in dietary fiber.

7. Sources of Dietary Fiber for Processed Foods

An increasing number of fiber sources are available for food processing, representing a diversity of sources and technological advances. Commercial food-grade purified cellulose products and cereal brans are used in food products to enhance the fiber content or for other functional purposes. Many purified or partially purified nondigestible polysaccharides are used in food systems for their physicochemical properties, for example, for viscosity or as suspending agents. These polysaccharides contribute to the dietary fiber content even though they are not used for that purpose.

7.1. Commercial Cellulose Products. High quality purified cellulose is prepared from soft or hard woods by pulping methods that remove most of the associated hemicelluloses, lignin, waxes, and other constituents. The pulp is then bleached to give a white cellulose (α-cellulose) that is a relatively pure (>90%) (1→4)-β-D-glucan. Although the main intent is to degrade and remove the lignin and hemicelluloses, the cellulose, too, may be partially depolymerized. Purified fibrous cellulose is white, odorless, and nonabrasive. Although devoid of flavor, it possesses an undesirable texture in the mouth related to its fibrous nature, particle size, and insolubility. Other cellulosic products are made from the cellulose pulp or α-cellulose.

Powdered Cellulose. Solka-Floc, a purified fibrous powdered cellulose, is said to be 99% cellulose on a dry weight basis, virtually lignin free, free of fat and protein, and with low ash content. Food grades are available in fiber lengths averaging 20–25 to 100–140 μm.

Microcrystalline Cellulose. Limited hydrolysis of fibrous cellulose pulp yields a product more highly crystalline than native cellulose. Mineral acids

hydrolyze glycosidic bonds in the less crystalline regions of the cellulose fibers. The resulting cellulose microcrystals can be mechanically dispersed in water to give a gel or emulsionlike colloidal suspension for use in low calorie whipped toppings as well as in low fat or fat-free emulsions that mimic oil-in-water emulsions at cellulose concentrations in the 0.75–3% range. These microcrystals, like the native cellulose, do not melt and can be used in food systems under heat-processing conditions that would destroy the emulsion stability of fat- and oil-based systems.

Microcrystalline celluloses are marketed under the trade name Avicel. The physical characteristics of microcrystalline celluloses differ markedly from those of the original cellulose. The free-flowing powders have particle sizes as small as 0.2–10 μm. Avicel celluloses coated with xanthan gum, guar gum, or carboxymethylcellulose to modify and stabilize their properties are also available. The Avicel products are promoted for use in low calorie whipped toppings and icings and in fat-reduced salad dressings and frozen desserts.

Cellulose Derivatives. Chemical modification markedly alters the physical properties of cellulose. Common derivatives include methylcellulose [9004-67-5], ethylcellulose [9004-57-3], propylcellulose [9005-18-9], hydroxyethylcellulose [9004-62-0], hydroxypropylcellulose [9004-64-2], and carboxymethylcellulose (CMC) [9000-11-7] as well as mixed ethers of cellulose. These derivatives are obtained by alkylation of the cellulose under basic conditions. The ether substituents disrupt the extensive hydrogen bonding in the cellulose and permit increased hydration. At certain degrees of substitution the insoluble cellulose is transformed into a water-soluble colloid. The nature and size of the substituent, the regularity of substitution, and the molecular weight of the cellulose determine the degree of substitution at which water solubility occurs. In addition to increased hydration, CMC displays increased ion-exchange capacity. These cellulose ethers are used in food products for enhanced water retention, reduction of oil absorption in fried foods, and as thickeners and binders.

Bacterial Cellulose. Development of a new strain of Acetobacter may lead to economical production of another novel cellulose. Cellulon fiber has a very fine fiber diameter and therefore a much larger surface area, which makes it physically distinct from wood cellulose. Its physical properties more closely resemble those of the microcrystalline celluloses; thus it feels smooth in the mouth, has a high water-binding capacity, and provides viscous aqueous dispersions at low concentration. It interacts synergistically with xanthan and CMC for enhanced viscosity and stability.

7.2. Bran. Bran fractions are more concentrated sources of fiber than are grain flours. A process for producing flour with increased total dietary fiber has been described (21). As a fiber supplement in foods, cereal grain brans are more representative of natural dietary fiber than is cellulose because bran contains hemicelluloses, lignin, and cellulose. The composition and properties of bran are dependent on the cereal grain source, plant variety, and milling practices. Varying amounts of the endosperm components are present, and the particle size depends on the break roll from which the bran is taken. Wheat bran contains a large proportion of arabinoxylans, considerable lignin, and some starch in addition to cellulose. Wheat brans are readily available from any flour mill. Brans

from corn, oats, barley, and rice are also available and differ from wheat bran in composition and properties. Oat bran and barley bran, for example, contain high proportions of (1→3), (1→4)-β-D-glucans, part of which is soluble fiber, and little or no pectin. Oatrim products, developed at the National Center for Agricultural Research (ARS), Peoria, Illinois, contain up to 10% of the β-glucan. Rice brans are available in grades ranging from defatted bran (0.5–1.5% oil, 30–40% TDF) to stabilized full fat (18–22% oil, 25–30% TDF). Oat, barley, and rice brans contain significant amounts of soluble fiber, in contrast with wheat bran.

The American Association of Cereal Chemists has made available a certified food grade wheat bran as a reference standard for research purposes. This bran is a blend of soft white wheat (87.3%) and club white wheat (12.7%).

7.3. Other Insoluble Fiber Sources. Other insoluble fiber sources are commercially available as well, including fiber from sugar-beet pulp, a by-product of sugar production. Table 2 lists other insoluble fiber sources.

7.4. Sources of Functional Polysaccharides Contributing to SDF. Polysaccharides of diverse and frequently complex structure and origin are used as food additives for their functional properties, viscosity, emulsification, bodying and suspending, water binding, gelation, and fat-mimicking texture. They are used at relatively low levels (up to about 3%) and are regulated by the FDA for specific functional purposes. These polysaccharides tend to be water-soluble and contribute to SDF. They are usually classified by source, that is, seaweed or algal, microbial, plant exudate, legume seeds, and tubers. The more commonly used gums and mucilages are listed in Table 3.

8. Specific Food Sources of Dietary Fiber

Food sources of dietary fiber ranked by grams of dietary fiber per standard amount; also calories in the standard amount are listed in Table 4. All are >10% of AI (adequate intake) for adult women, which is 25 g/day.

9. Fiber Supplements

There are many types of soluble fiber supplements available to consumers. They include: psyllium seed husk; methylcellulose; inulins; and vegetable gums.

Psyllium seed husk (sold under the brand names, Metamucil and Konsyl) may reduce heart disease by lowering cholesterol. The FDA allows foods containing 0.75 g of psyllium husk soluble fiber to claim reduced risk of heart disease from regular consumption.

Methylcellulose is created from cell walls of plants and it is sold as a powder. It is sold under the brand names of Citrucel and Celevac.

Inulins are a group of oligosaccharides occurring naturally in many plants. Inulin belongs to a class of carbohydrates known as fructans. It is used increasingly in prepared foods.

Vegetable gums are new to the market and are sold as a powder. They dissolve readily with no aftertaste. Examples are guar gum (Benefiber) and acacia gum.

BIBLIOGRAPHY

"Dietary Fibers" in *ECT* 3rd ed., Vol. 7, pp. 628–638, by B. Lewis, Cornell University; "Dietary Fiber" in *ECT* 4th ed., Vol. 8, pp. 137–148, by B. A. Lewis, Cornell University, "Dietary Fiber" in *ECT* (online), posting date: December 4, 2000, by B. A. Lewis, Cornell University.

CITED PUBLICATIONS

1. H. Trowell, *Nutr. Rev.* **35**, 6 (1977).
2. Linus Pauling Institute, Oregon State University http://oregonstate.edu/infocenter/phtyochemicals/fiber/, accessed April 2007.
3. R. J. Redgwell and M. Fischer, *Molecular Nutrition Food Research* **49**(6), 521–535 (2005).
4. P. J. Van Soest and R. H. Wine, *J. Assoc. Off. Anal. Chem.* **50**, 50 (1967).
5. *AOAC Official Methods of Analysis*, 15th ed., Washington, D.C., 1990, 1105–1106; 3rd Suppl., 1992.
6. L. Prosky and co-workers, *J. Assoc. Off. Anal. Chem.* **68**, 677 (1985).
7. R. R. Selvendran, *Amr. J. Clin. Nutr.* **39**, 320 (1984).
8. A. Bacic, P. J. Harris, and B. A. Stone, in J. Preiss, ed., *The Biochemistry of Plants*, Vol. **14**, Academic Press, New York, 1988, 297–370.
9. A. M. Stephen, in G. O. Aspinall, ed., *The Polysaccharides*, Vol. **2**, Academic Press, New York, 1983, Chapt. 3.
10. D. E. King, *Molecular Nutrition Food Research* **49**(6), 594–600 (2005).
11. A. A. Salyers, S. E. H. West, J. R. Vercellotti, and T. D. Wilkins, *Appl. Environ. Microbiol.* **34**, 529 (1977); **33**, 319 (1977).
12. D. F. Hentges, ed., *Human Intestinal Microflora in Health and Disease*, Academic Press, New York, 1983.
13. D. A. Rees, E. R. Morris, D. Thom, and J. K. Madden, in G. O. Aspinall, ed., *The Polysaccharides*, Vol. **1**, Academic Press, New York, 1982, Chapt. 5.
14. A. A. McConnell, M. A. Eastwood, and W. D. Mitchell, *J. Sci. Food Agric.* **25**, 1457 (1974).
15. D. Schaller, *Food Prod. Develop.* **11**, 70 (1977).
16. P. J. Van Soest, J. B. Robertson, and B. A. Lewis, *J. Dairy Sci.* **74**, 3583 (1991).
17. R. Mongeau and R. Brassard, *J. Food Comp. Anal.* **2**, 189 (1989).
18. J. L. Jeraci, B. A. Lewis, P. J. Van Soest, and J. B. Robertson, *J. Assoc. Off. Anal. Chem.* **72**, 677 (1989).
19. O. Theander and E. A. Westerlund, *J. Agric. Food Chem.* **34**, 330 (1986).
20. H. N. Englyst and J. H. Cummings, *J. Assoc. Off. Anal. Chem.* **71**, 808 (1988).
21. U.S. Pat. Appl. 20060263503 (Nov. 23, 2006), M. K. Oloniewska and co-workers (to National Starch and Chemical Co.).
22. *Dietary Guidelines for Americans*, USDA, http://www.health.gov/dietaryguidelines/, appendix B-8, updated Feb. 5, 2007.

GENERAL REFERENCE

S. S. Cho and M. I. Dreher, eds., *Handbook of Dietary Fiber*, Marcel Dekker, Inc., New York, 2001.

B. A. LEWIS
Cornell University

Updated by Staff

Table 1. **Polysaccharides of Land Plants**

Polysaccharide	CAS Registry Number	Structure
	Structural	
cellulose	[9004-34-6]	(1→4)-β-D-glucan
hemicelluloses	[9034-32-6]	
xylan	[9014-63-5]	(1→4)-β-D-xylan
arabinoxylan	[98513-12-3]	(1→4)-β-D-xylan with 3-linked α-L-arabinose branches
glucuronoarabinoxylans		(1→4)-β-D-xylan with 2-linked 4-*O*-methyl-α-D-glucuronic acid and arabinose branches
xyloglucan	[37294-28-3]	(1→4)-β-D-glucan with 6-linked α-D-xylose branches
β-glucans	[55965-23-6]	(1→3), (1→4)-β-D-glucan
pectic substances[a]	[9046-38-2]	(1→4)-α-D-galacturonan
	[39280-21-2]	(1→2)-L-rhamno-(1→4)-α-D-galacturonan
associated polysaccharides[a]		
arabinan	[9060-75-7]	(1→5)-α-L-arabinan with 3-linked α-L-arabinose branches
arabinogalactan	[9036-66-2]	(1→4)-β-D-galactan with α-L-ara-(1→5)-α-L-ara-(1→3)-L-arabinose branches
galactan	[9051-94-9]	(1→4)-β-D-galactan
	Nonstructural	
fructan	[9005-80-5],	(2→1)-β-D-fructan
	[9013-95-0]	(2→6)-β-D-fructan
galactomannan	[11078-30-1]	(1→4)-β-D-mannan with single 6-linked α-D-galactose branches
glucomannan	[37230-82-3]	(1→4)-β-D-glucomannan

[a]The rhamnogalacturonans are associated physically and covalently with associated polysaccharides. Several less common sugars are also covalently linked to the polysaccharide complex.

Table 2. **Other Insoluble Fiber Sources**

Source	Trade name	TDF, %
sugar-beet pulp	Fibrex	74[a]
soybean cotyledons	Fibrin	75[b]
pea fiber		90

[a]24% soluble fiber, primarily pectic polysaccharides.
[b]TDF primarily composed of pectin and associated polysaccharides.

Table 3. **Commercial Food Additive Sources of Soluble Polysaccharides**

Source	Gum/mucilage	Polysaccharide composition[a]
algae (seaweed)		
	agar	anhydro-L-Gal, Gal
	alginates	L-GulA, ManA
	carrageenan	anhydro-Gal, Gal
microbial		
	gellan	Glc, GlcA, L-Rha
	xanthan	Glc, GlcA, Man
plants		
exudate gums		
	arabic	L-Ara, Gal, GlcA, 4-0-methyl-GlcA, L-Rha
	ghatti	L-Ara, Gal, GlcA, Man, Xyl
	karaya	Gal, GalA, GlcA, L-Rha
	tragacanth	arabinogalactan + tragacanthic acid (L-Fuc, Gal, GalA, Xyl)
legume seeds		
	guar gum	galactomannan
	locust bean (carob)	galactomannan
other		
	konjac flour	glucomannan
	pectin	rhamnogalacturonan
synthetic/chemically modified		
	polydextrose	Glc
	modified celluloses	Glc

[a]Principal polysaccharide constituent listed. Sugars are D- unless otherwise noted. Ara = arabinose; Gal = galactose; GalA = galacturonic acid; Glc = glucose; GlcA = glucuronic acid; GulA = guluronic acid; Man = mannose; ManA = mannuronic acid; Rha = rhamnose; Xyl = xylose; Fuc = fucose.

Table 4. **Food Sources of Dietary Fiber**

Food	Standard amount	Dietary fiber, g	Calories
navy beans, cooked	½ cup	9.5	128
bran ready-to-eat cereal (100%)	½ cup	8.8	78
kidney beans, canned	½ cup	8.2	109
split peas, cooked	½ cup	8.1	116
lentils, cooked	½ cup	7.8	115
black beans, cooked	½ cup	7.5	114
pinto beans, cooked	½ cup	7.7	122
lima beans, cooked	½ cup	6.6	108
artichoke, globe cooked	1 each	6.5	60
white beans, canned	½ cup	6.3	154
chickpeas, cooked	½ cup	6.2	135
great northern beans, cooked	½ cup	6.2	105
cowpeas, cooked	½ cup	5.6	100
soybeans, mature cooked	½ cup	5.2	149
bran ready-to-eat cereals, various	~1 oz	2.6–5.0	90–108
crackers, rye wafers, plain	2 wafers	5.0	74
sweetpotato, baked, with peel	1 medium (146 g)	4.8	131
Asian pear, raw	1 small	4.4	51
green peas, cooked	½ cup	4.4	67
whole-wheat English muffin	1 each	4.4	134
pear, raw	1 small	4.3	81
bulgur, cooked	½ cup	4.1	76
mixed vegetables, cooked	½ cup	4.0	59
raspberries, raw	½ cup	4.0	32
sweetpotato, boiled, no peel	1 medium (156 g)	3.9	119
black berries, raw	½ cup	3.8	31
potato, baked, with skin	1 medium	3.8	161
soybeans, green, cooked	½ cup	3.8	127
stewed prunes	½ cup	3.8	133
figs, dried	¼ cup	3.7	93
dates	¼ cup	3.6	126
oat bran, raw	¼ cup	3.6	58
pumpkin, canned	½ cup	3.6	42
spinach, frozen, cooked	½ cup	3.5	30
shredded wheat ready-to-eat cereals, various	~1 oz	2.8–3.4	96
almonds	1 oz	3.3	164
apple with skin, raw	1 medium	3.3	72
brussels sprouts, frozen, cooked	½ cup	3.2	33
whole-wheat spaghetti, cooked	½ cup	3.1	87
banana	1 medium	3.1	105
orange, raw	1 medium	3.1	62

(*Continued*)

Table 4. (*Continued*)

Food	Standard amount	Dietary fiber, g	Calories
oat bran muffin	1 small	3.0	178
guava	1 medium	3.0	37
pearled barley, cooked	½ cup	3.0	97
sauerkraut, canned, solids, and liquids	½ cup	3.0	23
tomato paste	¼ cup	2.9	54
winter squash, cooked	½ cup	2.9	38
broccoli, cooked	½ cup	2.8	26
parsnips, cooked, chopped	½ cup	2.8	55
turnip greens, cooked	½ cup	2.5	15
collards, cooked	½ cup	2.7	25
okra, frozen, cooked	½ cup	2.6	26
peas, edible-podded, cooked	½ cup	2.5	42

[a] Ref. 21.