III. ISSUES IN DEFINING DIETARY FIBER

A careful analysis of the definitions of dietary fiber previously discussed reveals that there are a number of important ways in which one definition differs from another. These differentiating characteristics involve whether the following are included: animal carbohydrates, carbohydrates not recovered by alcohol precipitation, mono- and disaccharides, lignin, and resistant starch, and whether the fiber has to be intact and naturally occurring in food. Resistance to human endogenous digestive enzymes is specified in only some definitions. Some definitions require that a fiber have specific physiological effects, whereas others do not. How each definition has dealt with these issues is summarized in Table 3. Discussion and resolution of each of these differences among existing definitions formed the basis for the proposed definitions.

Animal versus Plant Material

Traditionally, the definition of dietary fiber has included only plant substances (Health and Welfare Canada, 1985; LSRO, 1987; Trowell et al., 1976). However, due to the limited methodological approaches that were developed, the accepted methods of measuring dietary fiber do not exclude substances that are not plant based. Thus, compounds like chitosan or glycosaminoglycans (i.e., mucopoly-saccharides) derived from animals are included in the fiber analytical values (Table 2). High fiber foods traditionally consumed in a Western diet contain negligible amounts of animal polysaccharides. But, as animal compounds are isolated and marketed as dietary supplements, animal sources that analyze as dietary fiber are becoming more significant. Polysaccharides from animals, yeast, bacteria, and agricultural by-products may all be similar in chemical structure to some components that make up the fiber found in plant foods. Although there has been no thorough evaluation, it can be assumed that animal-derived carbohydrate polymers analyze as dietary fiber by existing fiber methods. Definitions of dietary fiber thus include nondigestible animal carbohydrates (Table 3) in one of two ways: (1) they are part of dietary fiber for all definitions that are based on methods that precipitate polysaccharides with ethanol or measure monosaccharide constituents in the fiber residue, or (2) they are included because the definition does not specify plant components.

As interest in dietary fiber increases, economic incentives drive the development and subsequent marketing of more potential fiber products. Currently in the United States, but not in Canada, if these products assay as fiber by accepted methods, they are included as part of the total fiber content of foods. Furthermore, there are few data from human studies comparing animal-based with plant-based fibers using physiological endpoints. Until such data are available, the role of these animal fiber sources cannot be determined.

Carbohydrates Not Recovered by Alcohol Precipitation

Because many current definitions are based on methods involving ethanol precipitation, oligosaccharides and fructans that are endogenous in foods, but soluble in ethanol, are not analyzed as dietary fiber. Yet endogenous human enzymes do not digest fructans which are found in plants such as chicory, onions, and Jerusalem artichoke; thus they are included in many definitions (Table 3). Quantitation of fructans will be incomplete, even if the constituent monosaccharides of fructans are measured by a procedure that does not include ethanol precipitation, because the fructose component of fructans is labile in many acid hydrolysis procedures used during fiber analysis. Furthermore, fructose can be reduced to sorbitol and mannitol during preparation of derivatives for gas chromatographic analysis.

The oligosaccharides raffinose, stachyose, and verbacose that occur naturally in legumes and a variety of manufactured and enzymatically produced short-chain polysaccharides (e.g., fructooligosaccharides and partially hydrolyzed inulin and guar gum) also do not precipitate in ethanol. Several manufactured carbohydrates, such as methylcellulose, polydextrose, and oligosaccharides, are also resistant to human enzymatic hydrolysis. This would classify them as fiber under may definitions; however, they are not routinely analyzed as dietary fiber because they do not precipitate in ethanol.

No uniform approach has been developed to resolve the issue of fiber carbohydrates that do not precipitate in ethanol, even though many of these naturally occurring, hydrolyzed, or manufactured components are not analyzed as fiber but are considered to be fiber by many definitions. Recent analytical efforts have been directed toward the measurement of a specific carbohydrate or product, such as polydextrose or fructooligosaccharides. This individual approach has resulted in a proliferation of methods, some of which would overlap if applied to a product containing several manufactured or modified carbohydrates.

Inclusion or Exclusion of Mono- and Disaccharides

Typically, mono- and disaccharides have been found to be digestible by humans, and they do not precipitate in ethanol. Thus, no definition, except that used in China, includes these carbohydrates as dietary fiber (Table 3). However, chemical and enzymatic modification of saccharides normally digested and absorbed in humans, such as glucose, or hydrolysis of fiber polysaccharides, such as a gum or inulin, result in mixtures that may contain monosaccharides and disaccharides that are not fully digested and absorbed. Theoretically, monosaccharides, such as arabinose, mannose, xylose, and galacturonic acid, that make up many fiber polysaccharides would be passively absorbed in the human small intestine, although unknown quantities would still reach the large intestine. Without

TABLE 3 Characteristics of Various Dietary Fiber Definitions[a]

Reference	Nondigestible Animal CHOs[b]	CHOs Not Recovered by Alcohol Precipitation[c]	Nondigestible Mono- and Disaccharides
Trowell et al., 1976	No	Not considered	Not considered
Health and Welfare Canada, 1985	No	Not considered	Not considered
U.S. Food and Drug Administration (USFDA), 1987[d]	Yes	Some inulin	No
Life Sciences Research Office (LSRO), 1987	No	No	No
Health Canada, 1988	Yes	Implied[e]	Not considered
Anonymous, 1989 (Germany)	No	No	No
Anonymous, 1992 (Belgium)	Yes	Yes	No
Anonymous, 1993 (Italy)	No	Yes	No
FAO/WHO, 1995 (Codex Alimentarius Commission)[d]	Yes	Some inulin	No
Jian-xian, 1995 (China)	Yes	Yes	Yes
Denmark, 1995[d,f]	Yes	Some inulin	No
Ministry of Health and Welfare, 1996 (Japan)[d]	Yes	Yes	No
Committee on Medical Aspects of Foods (COMA), 1998 (United Kingdom)[d]	Yes	No	No
Finland, 1998[d,f]	Yes	Labeled separately, some inulin	No
Norway, 1998[d,f]	Yes	Inulin and oligofructose	No
Sweden, 1999[d,f]	Yes	Some inulin	No
American Association of Cereal Chemists (AACC), 2000	Yes	Yes	No
Hignett, 2000 (U.K. Food Standards Agency)[c]	Yes	Some inulin	No

Lignin	Resistant Starch	Intact, Naturally Occurring Food Sources Only	Resistant to Human Enzymes	Specifies Physiological Effect
Yes	Not considered	Not specifically listed	Yes	No
Yes	Not specifically listed	Yes	Yes	No
Yes	Some	No	No	No
Yes	No	Yes	Yes	No
Implied	Implied	No	Implied	No
Yes	Yes	No	Yes	No
Yes	Yes	No	Yes	No
Yes	Yes	No	Yes	No
Yes	Some	No	Yes	No
Yes	Yes	No	Yes	No
Yes	Some	No	No	No
Yes	Some	No	No	No
No	No	No	No	No
Yes	Some	Implied	Implied	No
Yes	Some	No	No	No
Yes	Some	No	No	No
Yes	Yes	No	Yes	Yes
Yes	Some	No	No	No

continued

TABLE 3 Continued

Reference	Nondigestible Animal CHOs[b]	CHOs Not Recovered by Alcohol Precipitation[c]	Nondigestible Mono- and Disaccharides
Australia New Zealand Food Authority (ANZFA) (Proposed), 2000	Yes	Yes	No
Institute of Medicine (Proposed), 2001			
Dietary Fiber	No	Yes	No
Added Fiber	Yes	Yes	Yes

[a] All definitions are assumed to include nonstarch polysaccharides.
[b] CHO = carbohydrate.
[c] Includes inulin, oligosaccharides (3–10 degrees of polymerization), fructans, polydextrose, methylcellulose, resistant maltodextrins and other related compounds.

specific disaccharidases, it is unlikely that disaccharides of these fiber-derived sugars or chemically modified disaccharides of glucose could be digested in the human small intestine. Because these mono- and disaccharides are nondigestible or poorly absorbed in the human small intestine, they could be classified as fiber.

The issue of including special mono- and disaccharides as dietary fiber has not been resolved. Methodological differentiation of digestible and nondigestible mono- and disaccharides will be cumbersome and complex to accomplish. Furthermore, these materials physiologically act as classic osmotically active agents in the gut, much in the same way that sugar alcohols do, and this response has not previously been considered a mechanism of action for dietary fiber.

Lignin

Although not a carbohydrate, lignin, a phenylpropane polymer, is typically included in the definition of dietary fiber (Table 3). Lignin is covalently bound to fibrous polysaccharides (Jung and Fahey, 1983) and has a heterogeneous composition ranging from one or two units to many phenyl propanes that are cyclically linked. These two characteristics have probably formed the basis for defining lignin as dietary fiber. Furthermore, although lignin is present in the human food supply in very small amounts, animal research with high fiber feeds has shown that lignin affects the physiological effects of dietary fiber. For example, lignin hinders fermentation of fiber polysaccharides in ruminants (Titgemeyer et al., 1991).

Lignin	Resistant Starch	Intact, Naturally Occurring Food Sources Only	Resistant to Human Enzymes	Specifies Physiological Effect
Yes	Yes	No	Yes	Yes
Yes	Some	Yes	Yes	No
Yes	Yes	No	Yes	Yes

[d] Method-based definition.
[e] Implied means not stated but inferred.
[f] N-G Asp, Division of Applied Nutrition, Lund University, personal communication, February 22, 2001.

Resistant Starch

The early definitions for dietary fiber did not consider resistant starch as its presence was not yet recognized (Table 3). Only the definitions proposed by LSRO (1987) and COMA (1998) specifically exclude resistant starch. The 1998 COMA definition is based on the Englyst method of analysis, which removes all starch from the fiber residue by solubilization with dimethyl sulfoxide. Some definitions, such as those of Germany and AACC, include resistant starch by specifically listing it; for others, such as those used in Belgium, Italy, and China, the wording of the definition indicates that resistant starch is part of fiber. Most other definitions, including the definition from the U.K. Food Standards Agency (Hignett, 2000), incorporate variable amounts of resistant starch as dietary fiber because they are based on AOAC procedures that do not analyze a portion of starch during fiber analysis (AOAC 991.43 and 997.08).

Depending on one's chosen diet, naturally occurring and manufactured resistant starch, as well as that produced during normal processing of foods for human consumption, could make a significant contribution to daily fiber intake. Legumes are the single largest source of naturally occurring resistant starch (Marlett and Longacre, 1996). In addition, green bananas (Englyst and Cummings, 1986) and cooled, cooked potatoes (Englyst and Cummings, 1987) can provide a significant amount of resistant starch. Resistant starch resulting from normal processing of a foodstuff is a more modest contributor to a typical daily intake. Starches specifically manufactured to be resistant to endogenous human digestion are a rapidly growing segment of commercially available resistant starches. Physiological effects and analysis of resistant starch are being intensively studied (Asp, 1997). Several issues remain to be addressed in these research areas, particularly for the emerging manufactured resistant starches. The development of an analytical method that reflects the extent of their digestion in vivo in the human stomach and small intestine is also needed.

Intact and Naturally Occurring in Food

The dietary fiber hypotheses of Burkitt and colleagues (1972) and Trowell (1972) were based on populations consuming unrefined diets that were high in dietary fiber and slowly digested carbohydrates. Fiber-rich foods, however, contain micronutrients and many other biologically active compounds that have distinct physiological and biochemical effects in humans. Furthermore, fiber integrated into plant cellular structure is released or becomes a viable force in the gastrointestinal tract only as digestible nutrients are hydrolyzed during digestion. These two features of fiber-rich foods are undoubtedly contributors to some of the health benefits usually attributed to dietary fiber.

As interest has increased in fiber, manufacturers have isolated dietary fiber from a wide range of carbohydrate sources to be added to foods. Many of these isolated materials are used as food additives based on functional properties such as thickening or fat reduction. As enzymatic and other technologies evolve, many types of polysaccharides will continue to be designed and manufactured using plant and animal synthetic enzymes. Examples in this category include modified cellulose in which the hydroxyl groups on the glucose residues have been substituted to varying degrees with alkyl groups such as methyl and propyl; fructooligosaccharides manufactured from sucrose; and polydextrose synthesized from glucose. In some instances, fibers isolated from plants or manufactured chemically or synthetically have demonstrated more powerful beneficial physiological effects than a food source of the fiber polysaccharide; in other instances, isolation from the plant matrix decreases physiological benefit.

Specificity of the various dietary fiber definitions with respect to non- or undigestibilty of the material varies among definitions (Table 3). Twelve of the current definitions specify or imply resistance to human enzymes, and seven do not. Some experts believe that resistance to human endogenous enzymatic digestion is a necessary component of the definition to ensure that degradation (i.e., fermentation) occurs in the human large intestine through the metabolism of fiber by the resident microflora.

Requirement that a Fiber have Specific Health Benefits

Two recent promulgated definitions (AACC, 2000; ANZFA, 2000) have specific health benefits necessary for a material to be labeled or considered to be dietary fiber (Table 3). However, origins of the current interest in dietary fiber came from observations that populations that consumed diets high in dietary fiber had reduced incidence of several chronic diseases common in Western populations. Correlational studies compared the incidence of heart disease, colon cancer, diverticular disease, diabetes, and other diseases with estimates of crude fiber in the diet of rural African populations and the United States (Burkitt et al., 1974). Since the health benefits of dietary fiber will be extensively reviewed in the upcoming report on Dietary Reference Intakes for macronutrients, only those health benefits previously considered and relevant to the fiber definition are briefly discussed here.

Colonic Health

One of the oldest recognized effects of dietary fiber is modulation of intestinal function. Dietary fiber alters water content, viscosity, and microbial mass of intestinal contents, resulting in changes in the rate and ease of passage through the intestine. The result of increased fiber includes reduced transit time, increased fecal weight, and improved laxation (Birkett et al., 1997), which, along with dilution of lumenal contents, have been proposed to reduce colon cancer risk (Trock et al., 1990). The accompanying reduction in intracolonic pressure may lower diverticular disease risk (Brodribb and Humphreys, 1976). By comparing effects of many different fiber sources, it has become apparent that those fibers that are slowly, incompletely, or not fermented significantly increase stool output; these fibers usually analyze as insoluble fibers and contrast with soluble fibers, most of which are rapidly fermented.

Correlational epidemiological evidence suggests a relationship between dietary fiber intake and colon cancer incidence (Trock et al., 1990), but more refined case control studies have observed a less consistent effect (Lanza, 1990). Furthermore, epidemiological observations suggest that formation of adenomatous polyps, a precancerous colonic lesion, is related to dietary fiber intake (Giovannucci et al., 1992), but colon cancer incidence is not (Giovannucci et al., 1994). Two recently published intervention trials, of 3 years duration, found no effect of fiber on the recurrence of adenomatous polyps in subjects given a wheat bran fiber supplement (Alberts et al., 2000) or in subjects who consumed a diet low in fat and high in fruits, vegetables, and fiber (Schatzkin et al., 2000). Wheat bran has been shown to reduce concentrations of fecal bile acids (Alberts et al., 1996), which have been implicated as carcinogenic promoters or cocarcinogens. In summary, the body of evidence indicates that slowly digested or nonfermentable fiber sources promote laxation, but evidence is insufficient to determine if decreased colon cancer risk is a beneficial effect of fiber. The complex etiology of colon cancer and the significant genetic involvement make the design of appropriate intervention trials very difficult except through the use of alternate end points, which has thus far been unsuccessful.

Breast Cancer

Some evidence has also accumulated suggesting a relationship between dietary fiber consumption and breast cancer risk (Gerber, 1998). However, this relationship is less consistent than that of fiber and colon cancer. Although intervention trials suggest an ability of fiber to reduce blood estrogen concentration, which is a risk factor for the development of breast cancer (Rose et al., 1991), data are not sufficient to suggest that high fiber diets lower breast cancer risk.

Cardiovascular Disease

A relatively large body of experimental data (Anderson et al., 2000; Olson et al., 1997; Ripsin et al., 1992) support a blood cholesterol-lowering effect of viscous dietary fibers that usually analyze as soluble fibers, and epidemiological evidence supports the relationship between increased intake of foods high in fiber and decreased risk of cardiovascular disease (Rimm et al., 1996; Wolk et al., 1999). In contrast, intervention with wheat bran had no significant effect on blood cholesterol concentrations (Anderson et al., 1991), failing to support an epidemiological benefit on cardiovascular disease incidence.

Using blood cholesterol concentrations as a marker for cardiovascular disease, certain fibers have beneficial physiological effects by lowering blood cholesterol, probably by modifying sterol balance (Anderson et al., 1984; Everson et al., 1992; Marlett et al., 1994). Experiments using viscous isolated polysaccharides (e.g., pectin, psyllium, guar gum) as a fiber source have demonstrated that many retain this hypocholesterolemic characteristic in the isolated form (Brown et al., 1999). Some evidence also suggests an inverse relationship between fiber and hypertension, another risk factor for cardiovascular disease (Ascherio et al., 1992, 1996). It is unclear whether fiber itself or substances associated with fiber-rich foods, such as phytochemicals and minerals, may be the important factors in the effects observed in these epidemiological studies.

Diabetes

The role of high fiber diets in reducing risk for Type 2 diabetes mellitus and for treatment of both forms of diabetes also relates to viscosity. Viscous fibers from food reduce glycemic response better than sources rich in nonviscous fibers (e.g., cellulose and lignin) (Wolever and Jenkins, 1993), and increase insulin sensitivity (Fukagawa et al., 1990). Increased viscosity results in slower stomach emptying, slower rate of absorption, and changes in the composition of colonic microbial flora (Roberfroid, 1993). Epidemiological studies have found that high glycemic load and low cereal fiber consumption is positively correlated with risk of Type 2 diabetes (Salmerón et al., 1997a, 1997b). In addition, blood glucose concentrations are reduced and exogenous insulin needs are lower when individuals with Type 2 diabetes consume higher fiber diets (Anderson and Ward, 1979). The beneficial physiological effects of viscous fibers on blood glucose concentrations have been consistently demonstrated for over 25 years and are supported by more mechanistic studies.

Hydrolysis reduces viscosity of guar gum and mixed linkage β-glucan (Jenkins et al., 1978; Wood et al., 1994) and hydrolyzed versions are now available because the lower viscosity may increase potential for additional food uses. However, what data exist on the physiological differences seen when polymeric chain length and viscosity are reduced suggest that the glycemic and cholesterol-lowering effects of fiber may be reduced or lost (Favier et al., 1997; Jenkins et al., 1978; Lund et al., 1989; Wood et al., 1994). Therefore, the advantages of improved palatability and ease of use must be weighed against potential loss of physiological effect for fibers that have a shorter chain length and reduced viscosity.

Obesity

A fiber-rich diet has been suggested to be an important factor in weight maintenance and the treatment of obesity (Appleby et al., 1998; Burley et al., 1993; Miller et al., 1994), although the significant changes in upper gastrointestinal tract function are difficult to consistently measure. Diets high in fiber are associated with slower stomach emptying, which induces a short-term increase in satiety (Roberfroid, 1993). This may modulate caloric intake and the rate of nutrient absorption. In addition, the reduced caloric density of diets rich in fiber has been suggested to be an asset in weight maintenance. Diets higher in fiber are just one aspect of the treatment of obesity, and at this time, measurable effects attributable solely to fiber are insufficient to designate fiber as a beneficial physiological effector of body weight.

Other Roles in Health

There are several other potential beneficial effects of fiber and fiber-like materials for which additional data are needed before the benefits can be substantiated. For example, some preliminary observational evidence suggests fiber may protect against duodenal ulcers (Aldoori et al., 1997) and gastric cardia cancer (Terry et al., 2001). Animal experiments have suggested a role of various fibers on intestinal immune function (Field et al., 1999; Lim et al., 1997), although human studies are lacking. As a result of fiber serving as substrate for bacteria in the large intestine, changes in the spectrum and mass of bacteria in the intestine have been a topic of discussion for some time (Roberfroid, 1993). As these changes are more thoroughly understood, the use of fibers to modify fecal and colonic bacteria, much like the suggested use of probiotics, may be possible.