Role of Fiber in Carbohydrate Quality—Meeting Dietary Fiber Recommendations: What Counts?

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To understand the contribution of dietary fiber to carbohydrate quality, it is useful to examine the definition of dietary fiber, how that definition has evolved, and what is currently accepted in recommendations for fiber intake by humans. Two aspects of dietary fiber have consistently emerged to define its quality and to provide a basis for recommendations for intake: fiber as a component of plant foods in the diet and fibers that have physiological effects that provide a health benefit.

Early Definitions of Dietary Fiber

In early literature from the late 1800s and early 1900s fiber was identified as a component of carbohydrates in the diet and was characterized as cellulose or woody fibers (1). In these early evaluations of diet and nutrition, carbohydrates were primarily viewed as a source of energy and often regarded as less important in the diet than proteins or fats. However, in a 1917 guide on "How to Select Foods," Hunt and Atwater (8) state that fiber (cellulose) "gives bulk to the diet and may tend to prevent constipation… [and be] more satisfying to the appetite." The early characterization of fiber as cellulose was likely due to the use of a crude fiber method, which primarily measures cellulose, in food analysis. Cummings and Engineer (4) have published a review on the origins of the dietary fiber hypothesis in which they characterize the key steps in broadening our understanding of the complexity of dietary fiber and its contribution to health. The steps they characterize in this evolution include the work of McCance and Lawrence to identify the various carbohydrates, in addition to cellulose, that are associated with the plant cell wall and should be included as a component of fiber in the diet.

In addition, the analytical work conducted by David Southgate to determine available carbohydrates (i.e., starches and sugars that are digested by enzymes in the human digestive tract) and unavailable carbohydrates (i.e., carbohydrates that are not digested by enzymes secreted in the human small intestine) created a framework to examine the carbohydrates associated with dietary fiber that are meaningful in human nutrition. The concept of the digestibility of carbohydrates in the small intestine of humans became integral to the definition of dietary fiber and was central to the dietary hypothesis presented by Burkitt and Trowell in 1975 (2). Their definition states that "Dietary fibre has been defined as the remnants of the plant cell-wall that are not hydrolysed by the alimentary enzymes of man…. It is composed largely of celluloses, hemicelluloses, and lignin…. Dietary fibre is not the same as crude fibre…" (2).

This early work in defining dietary fiber resulted in the establishment of two elements of quality for dietary fibers: the association with plant cell walls and lack of digestibility in the human small intestine. In addition, the early definition of dietary fiber and the development of the dietary fiber hypothesis related to disease established a link between plant foods and dietary fiber consumption. As a consequence, most recommendations on fiber intake have emphasized the importance of consuming fiber from plant foods.

Updating the Definition of Dietary Fiber

The dietary fiber hypothesis put forward by Burkitt and Trowell (2) stimulated research to understand the impact of dietary fiber on health promotion and disease prevention and to determine whether dietary fibers have unique properties that affect human physiology and metabolism or whether they primarily serve as markers of a diet rich in plant foods. During this phase of research activity, several scientists observed that solubility was a potential way to characterize differences in various types of fibers. Fibers that were classified as soluble were characterized as swelling or dispersing in water, more likely to contribute to plasma cholesterol reduction and improved glycemic

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control, and highly fermentable in the large intestine. In contrast, insoluble fibers were characterized as not taking up water in the gastrointestinal tract, not readily degraded in the large intestine by microbial action, and more likely to improve laxation by increasing stool output. However, this categorization of fibers proved to be too simplistic for predicting the physiological effects of fibers, in part because various factors contribute to whether a fiber can be classified as soluble or insoluble, and most food sources contain a variety of fiber types (12).

In the Dietary Reference Intake (DRI) report for macronutrients, the Institute of Medicine (IOM) identifies viscosity and fermentability as two characteristics of fibers that are more likely to predict physiological effects associated with consuming dietary fiber that would result in health benefits (9). A review by McRorie and McKeown (12) summarizes the evidence that illustrates how these two characteristics (viscosity and fermentability) are associated with lowering blood lipids, improving glycemic control, and improving laxation. As outlined in their review, viscous soluble fibers, such as psyllium and β-glucan, are more likely to lower cholesterol concentrations and improve glycemic control, whereas low-viscosity or nonviscous, soluble fibers, such as methylcellulose or inulin, do not have this beneficial physiological effect. Likewise, insoluble fibers, such as those found in wheat bran, that are not extensively degraded by microbial action in the large bowel are more effective in improving laxation than fibers that are more completely fermented by microbes. McRorie and McKeown's analysis suggests that these characteristics of fibers are potentially useful indicators of quality; however, the fact that an analytical approach for accurately measuring these fiber properties has not been developed and standardized is a major limitation in using these characteristics (12).

The IOM approach, which influenced the regulatory process for defining dietary fiber in the United States, as well as the approaches taken by the Codex Alimentarious Commission and the European Union, have resulted in new definitions of fiber that extend beyond the association of fiber as a marker of a diet containing plant foods to include isolated and synthetic fibers that are ingredients in formulated foods or used as dietary supplements (3,6). These definitions, as summarized in Table I, introduce additional factors for understanding quality associated with dietary fiber. In this context, fibers that are intrinsic and intact in foods are considered, by their nature, to be dietary fiber and predominately include the fibers associated with the plant cell wall matrix. In addition, isolated or synthetic polysaccharides or oligosaccharides can be considered dietary fibers if they have been demonstrated to have a physiological effect that is of benefit to human health. These regulatory and standard-setting approaches to defining dietary fiber do not rely on the physical properties of fiber (i.e., viscosity or degree of fermentation) to define isolated and synthetic polysaccharides and oligosaccharides as dietary fibers, but instead rely on the part of the definition that focuses on a physiological effect that is beneficial to health. Examples of such benefits identified by the U.S. Food

Table I. Definitions of dietary fiber established by the Codex Alimentarious Commission, the European Union, and the U.S. Food and Drug Administration

Organization Publication	Definition
Codex Alimentarius Commission *Codex Guidelines on Nutrition Labelling, Section 2.8.* (CAC, 1985)	Dietary fibre means carbohydrate polymers[1] with ten or more monomeric units[2], which are not hydrolysed by the endogenous enzymes in the small intestine of humans and belong to the following categories: • Edible carbohydrate polymers naturally occurring in the food as consumed, • carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic or chemical means and which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities, • synthetic carbohydrate polymers which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities [1] When derived from a plant origin, dietary fibre may include fractions of lignin and/or other compounds associated with polysaccharides in the plant cell walls. These compounds also may be measured by certain analytical method(s) for dietary fibre. However, such compounds are not included in the definition of dietary fibre if extracted and re-introduced into a food. [2] Decision on whether to include carbohydrates from 3 to 9 monomeric units should be left to national authorities.
European Union *Commission Directive 2008/100/EC of 28 October 2008 amending Council Directive 90/496/EEC on nutrition labelling for foodstuffs as regards recommended daily allowances, energy conversion factors and definitions.* (Off. J. EU 285(29.10.2008), pp. 9-12)	For the purposes of this Directive 'fibre' means 'carbohydrate polymers with three or more monomeric units, which are neither digested nor absorbed in the human small intestine and belong to the following categories: – edible carbohydrate polymers naturally occurring in the food as consumed; – edible carbohydrate polymers which have been obtained from food raw material by physical, enzymatic or chemical means and which have a beneficial physiological effect demonstrated by generally accepted scientific evidence; – edible synthetic carbohydrate polymers which have a beneficial physiological effect demonstrated by generally accepted scientific evidence.'
U.S. Food and Drug Administration *Code of Federal Regulations. 21 CFR 101.9 (c)(6)(i), Nutrition labeling of food.* (22)	Dietary fiber is defined as non-digestible soluble and insoluble carbohydrates (with 3 or more monomeric units), and lignin that are intrinsic and intact in plants; isolated or synthetic non-digestible carbohydrates (with 3 or more monomeric units) determined by FDA to have physiological effects that are beneficial to human health.

and Drug Administration (FDA) include lowering blood glucose or cholesterol levels, lowering blood pressure, increasing feelings of fullness (satiety) resulting in reduced calorie intake, increased mineral absorption in the intestinal tract, and improved laxation and bowel function (21). The FDA guidance indicates that only one benefit must be demonstrated to make a carbohydrate eligible to be considered as dietary fiber in a food. If scientific evidence is available, additional physiological endpoints that provide a health benefit can be added to the list. The FDA has provided draft guidance on scientific evaluation of the evidence that, outlining an approach that is consistent with how the FDA has evaluated scientific evidence for substantiating nutrition-related claims on packaged foods (20).

Recommendations for Dietary Fiber Intake

As our understanding of the contribution that fiber makes in a health-promoting diet has evolved, what is counted as contributing to fiber intake has been updated, and recommendations for fiber intake have progressed from qualitative recommendations concerning plant foods to quantitative recommendations based on the quality of the fiber sources related to physiological function and on reduced risk of certain chronic diseases.

In the early 1900s crude fiber was recognized as a component of plant foods that might have a benefit for gastrointestinal regularity but was not viewed as essential in the diet. The dietary fiber hypothesis put forward by Burkitt and Trowell (2) indicated that more research was needed to understand the metabolic effects of dietary fibers beyond simply providing roughage in the diet. In the United States the recommendations for fiber intake, which were established as a part of the development of Recommended Dietary Allowances (RDAs), now referred to as DRIs by the National Academies of Science, Engineering, and Medicine, reflect this evolution of the scientific basis for the importance of fiber intake. The RDA reports published between 1968 and 1980 included fiber in the category of complex carbohydrates (cellulose and hemicelluloses), which were not considered as an essential nutrient but as a preferred source of carbohydrate in the diet relative to sugars and refined starches (13–15, 17). The 1989 RDA report recognized the need to increase fiber intake, with an emphasis on dietary fiber from foods not fiber concentrates (17). The 1989 report was informed by diet and health reports published by the National Research Council (16) and the surgeon general (19), both of which highlighted the association of risk for chronic diseases with diets lacking in dietary fiber. The 2005 DRI report on macronutrients published by the IOM (9) reaffirmed that fiber is not considered an essential nutrient for which inadequate intake can be assessed based on biochemical or clinical symptoms but did recognize that a lack of fiber intake detracts from optimal health and examined scientific evidence to establish an adequate intake (AI) level (as defined in the report, an AI is an estimated intake needed to sustain a defined nutritional state used when it is not feasible to establish an RDA). By evaluating the scientific evidence on the effects of fiber on laxation and gastrointestinal function, normalizing blood cholesterol, or attenuating blood glucose responses, the IOM determined that an AI of 14 g/1,000 kcal could be recommended for fiber intake to reduce the risk of coronary heart disease (9). The European Food Safety Authority (EFSA) concluded that an adequate intake for dietary fiber could be established based on bowel function and recommended that 25 g/day in adults (or 2–3 g/MJ) is adequate for laxation (6). On a more global level, in 2003 the Food and Agriculture Organization of the United Nations and the World Health Organization (FAO/WHO) (24) established population goals for carbohydrates, including dietary fiber, of 55–75% of energy intake. Although FAO/WHO did not establish a population goal for dietary fiber, a food-based recommendation to consume 25 g of fiber/day from plant foods such as fruits, vegetables, and whole grains was established, and these recommendations were reaffirmed in the 2007 update on carbohydrate intake recommendations (10).

Conclusions

Two primary factors determine the quality of dietary fiber as a component of carbohydrate. One aspect of quality is based on dietary fiber as a component of plant foods. The importance of consuming plant foods for adequate fiber intake is typically a component of food-based dietary guidelines (FBDG), such as the *Dietary Guidelines for Americans* (18). FBDG from many different countries consistently recommend fruits, vegetables, legumes, and whole grains, and the justifications for such recommendations include their contribution to dietary fiber intake, as well as essential nutrients, and to dietary patterns associated with disease risk reduction and health promotion (7). Epidemiological studies have associated the intake of plant foods with lower risk of chronic diseases. However, based on observational data it is not feasible to establish a cause-and-effect relationship for fiber and specific chronic diseases. In the context of FBDG, the contribution of fiber to carbohydrate quality is based on the foods that are included in dietary patterns to meet fiber recommendations.

Several analytical approaches are possible to determine the fiber content that is intrinsic and intact in foods, as required for food composition databases and food labeling (5,11). However, the updated definition of dietary fiber has allowed a second approach for determining dietary fiber quality, which is to evaluate the physiological effects related to health benefits. As implemented, this second approach for defining dietary fiber requires a regulatory approach to evaluate the scientific evidence supporting the health benefits of a fiber source rather than an analytical methodology. As recognized in the final rule for updating Nutrition Facts labels in the United States, fibers for which a health claim has been approved (β-glucan soluble fiber and psyllium husk) can be included in the total fiber content of a food (23). In addition the FDA has stated that adequate scientific justification exists to consider cellulose, guar gum, pectin, locust bean gum, and hydroxypropylmethylcellulose as meeting the dietary fiber definition and is in the process of considering evidence for an additional 26 isolated and synthetic nondigestible carbohydrates (20). If an isolated or synthetic nondigestible carbohydrate is considered as a dietary fiber, then AOAC methodology can be used to estimate the total fiber content of foods that contain the fiber (11). However, any analysis of the total fiber content of foods will need to be corrected for any isolated or synthetic nondigestible carbohydrates used as ingredients that are not considered dietary fiber because they have not been demonstrated to have a physiological effect beneficial to human health.

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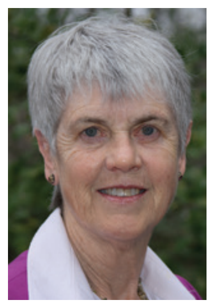

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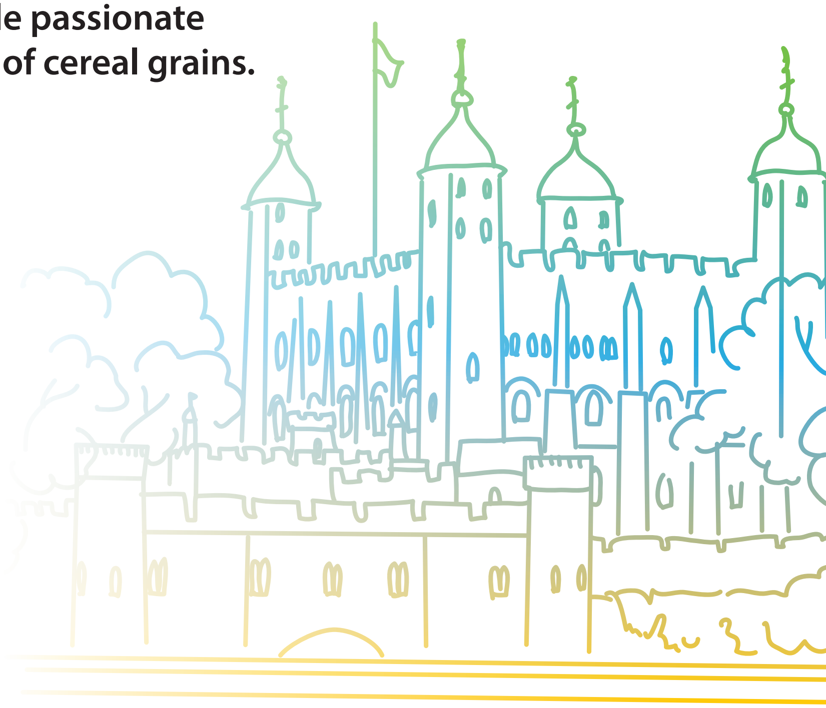

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