

Chapter 1

Introduction to Fiber and Nondigestible Carbohydrates: Definition, Health Aspects, and Perspectives

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Introduction

Carbohydrates for digestive health and/or fiber have come a long way since the first definition of dietary fiber was created by Hipsley in 1953 and expanded by Trowell and others in the early 1970s (Devries et al. 1999). These first definitions described the nondigestible components of plant cell wall material and associated compounds. In the following years, much information has been discovered with research regarding nondigestible carbohydrates and/or fiber (as well as other nondigestible substances) and how they nourish the body through fermentation in the large intestine. This is a very exciting time as more relationships between nondigestible carbohydrates, the human or the animal host, and gut microbiota are explored and brought to light. There is much more research necessary for further discoveries and aid in both human and animal digestive health.

We are using the term *nondigestible carbohydrate* in the contents of this book instead of or in addition to the term *fiber*, because some definitions of fiber preclude smaller nondigestible carbohydrates such as lactulose or galactobiose. These are classified as disaccharides and under most current regulatory rules, they qualify as sugar and not fiber, regardless of their digestibility or fermentability in the colon or glycemic impact. Furthermore, some nondigestible carbohydrates do not have

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analytical methods to quantify these substances as fiber using official American Organization of Analytical Chemists (AOAC) methods, although some of these may have the same benefits for digestive health as fibers that are quantified by AOAC methods. As an example, pectic and xylooligosaccharides have been suggested as possible prebiotics (see Chapter 9; Roberfroid 2009), but current AOAC fiber method analyses will not quantify these substances.

Fiber and nondigestible carbohydrates are tremendously difficult analytes because they are a group of compounds composed of a large number of carbohydrates with very different physical properties. Solubility in water and solvents of varying polarity can be very different, fiber structure can be highly branched or linear and vary by orders of magnitude in molecular weight and other factors cause difficulty in finding one analytical method that can analyze all types of fiber.

Fiber and nondigestible carbohydrates can be defined as those which are not digested (or minimally digested) in the stomach or small intestine and are carried on into the large intestine where they might be utilized by gut microbiota as substrates resulting in a number of metabolites. Some of these metabolites are utilized by the human host as energy, hormonal response stimulators, facilitators of mineral uptake, immune function enhancers, and other roles (Roberfroid 2009). Other metabolites are further utilized by gut microbiota themselves in cross-functional relationships where one species creates a metabolite and another uses that metabolite to create a different compound. These relationships are very complex and we are just beginning to understand the true role of the gut in human and animal health. Regardless of the definition or the ability to analyze nondigestible carbohydrates, the primary goal in studying them is to further enhance and develop human and animal health.

Physiological versus Analytical Definitions of Fiber

A good point to start exploring this topic is to consider the evolution of the definition of fiber, how it relates to health benefits, and the development of analytical methods. The definitions of fiber (as well as prebiotic) over time always stem from investigations into the potential health benefits. As more health benefits come to light and other nondigestible carbohydrates are identified as fermentable and/or prebiotic,

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better analytical methods will be developed. The need for better methods is driven by the definition and the definition is ultimately driven by health benefits. Excellent references in the history and development of the definition of fiber are available from many sources and a few key ones are cited here (Devries et al. 1999; Dietary Fiber Definition Committee 2001; Slavin 2003; Cui and Roberts 2009; Mann and Cummings 2009).

Table 1.1 contains some of the milestones in development of a fiber definition. Please note that not all researchers agreed on the definitions over time and it is still a matter of debate.

Hipsley is credited for creating the term *dietary fiber* in 1953, defining it as lignin, cellulose, and hemicellulose. The paper presented data on diets from several countries and time periods attempting to correlate fiber ingestion with the incidence of pregnancy toxemia, showing that diets high in fiber reduced incidence of the condition. The definition of fiber was broadened by Trowell, Burkitt, Painter, and others with research on diverticulitis (Painter and Burkitt 1971), transit time (Burkitt et al. 1972), cardiovascular disease (Trowell 1972) in subsequent years when a more encompassing definition was published in 1974 and expanded in 1976 as detailed in Table 1.1. The definitions were driven by Trowell's hypothesis and research on the health benefits of fiber on cardiovascular disease proposing that "Experiments in animals and man may be interpreted to support a suggestion that dietary fiber decreases the reabsorption of bile salts, increases fecal excretion, and reduces hyperlipidemia" (Trowell 1972). A few years later, Jenkins et al. (1980a, 1980b, 1980c) were experimenting with viscous soluble fiber (guar gum) and modification of glycemic response finding that guar gum at high levels greater than 20 g/day moderated glucose and insulin levels in diabetic patients and normal subjects. Clearly, the science around the health benefits of soluble fiber was advancing, showing health benefits of fiber beyond cellulose, hemicellulose, and lignin defined as dietary fiber by Hipsley in 1953.

Along with advances in scientific evidence of the health benefits of fiber, it became clear that better analytical methods needed to be developed as the current methods of the time were inadequate. Until 1985, there was no AOAC method specifically designed to analyze dietary fiber. Crude, acid, and neutral detergent methods for fiber were used to digest (hydrolyze) proteins, sugars, starch, and pectins from plant cell wall material. These are analytical wet chemistry methods for

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Table 1.1. Selected history of proposed definitions of fiber.

1953 Hipsley	Dietary fiber is lignin, cellulose, and hemicellulose.
1974/1976 Trowell et al.	1974 Structural polysaccharides: celluloses, also homopolysaccharides and heteropolysaccharides, formerly inaccurately classified as hemicelluloses. These unavailable carbohydrates are bound as a fine lattice work with gums and lignins: polymers based on phenylpropane units. Includes “Unavailable lipids: waxes and cutins, associated with fibre.” 1976 . . . dietary fiber should be redefined equally simply as the plant polysaccharides and lignin which are resistant to hydrolysis by the digestive enzymes of man. Dietary fiber includes storage polysaccharides, mucilages, and algal polysaccharides.
1985 Working definition of fiber (Devries et al. 1999)	AOAC Official Method of Analysis 985.29, Total Dietary Fiber in Foods—Enzymatic—Garavametric Method Adopted. Method and the equivalent AACC Approved method 32-05 become the <i>de facto working definition of fiber</i> .
2000 AACC definition issued	“Dietary fiber is the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fiber includes polysaccharides, oligosaccharides, lignin, and associated plant substances. Dietary fibers promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation.”
2002 Institute of Medicine	<i>Dietary Fiber</i> consists of nondigestible carbohydrates and lignin that are intrinsic and intact in plants. <i>Functional Fiber</i> consists of isolated, nondigestible carbohydrates that have beneficial physiological effects in humans. <i>Total Fiber</i> is the sum of <i>Dietary Fiber</i> and <i>Functional Fiber</i> .

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Table 1.1. (Continued)

2009 Codex definition	Dietary fiber means carbohydrate polymers ¹ with ten or more monomeric units, ² which are not hydrolyzed 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.
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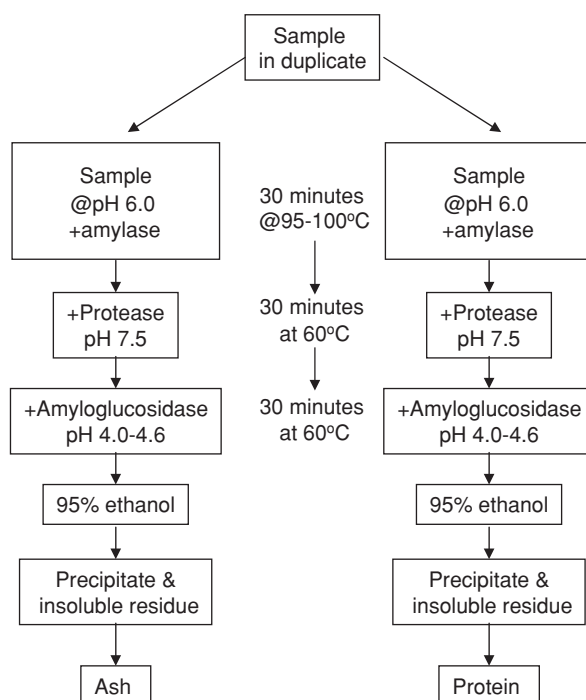
¹When derived from a plant origin, dietary fiber may include fractions of lignin and/or other compounds when associated with polysaccharides in the plant cell walls and if these compounds are quantified by the AOAC gravimetric analytical method for dietary fiber analysis: Fractions of lignin and the other compounds (proteic fractions, phenolic compounds, waxes, saponins, phytates, cutin, phytosterols, etc.) intimately “associated” with plant polysaccharides are often extracted with the polysaccharides in the AOAC 991.43 method. These substances are included in the definition of fiber insofar as they are actually associated with the poly- or oligosaccharidic fraction of fiber. However, when extracted or even reintroduced into a food containing nondigestible polysaccharides, they cannot be defined as dietary fiber. When combined with polysaccharides, these associated substances may provide additional beneficial effects (pending adoption of Section on Methods of Analysis and Sampling).

²Decision on whether to include carbohydrates with monomeric units *lower than* ten should be left to national authorities.

estimating fiber, not what is actually digested by mammalian enzymes in the upper gastrointestinal tract or the fraction that progresses undigested to the large intestine. These methods are still in use today for analyzing livestock feed.

The Trowell definition (1974, 1976) gained wide acceptance through international collaboration and became the basis definition for the first official AOAC International method (Devries et al. 1999) issued in 1985 as AOAC 985.29 and became the “defacto working definition

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$$\text{Total dietary fiber} = \text{Precipitate \& insoluble residue} - \text{protein-ash}$$

Figure 1.1. AOAC method 985.29: enzymatic/gravimetric method for fiber analysis.

of fiber” (Devries et al. 1999). As is shown in Figure 1.1 and Table 1.2, AOAC 985.29 is an enzymatic/gravimetric method using amylase, amyloglucosidase, and protease to digest what is not fiber.

It does not represent mammalian digestion, but it does constitute a standard method to analytically determine total dietary fiber (TDF) for labeling purposes and is still in use today. AOAC 985.29 does not distinguish between soluble and insoluble fibers, but simply measures TDF. As the evidence for benefit of soluble fibers increased over the years with research on oat beta glucan (Wood 1991; Brennan and Cleary 2005), and other soluble fibers such as pectin, guar, and psyllium (Theuwissen and Mensink 2008), a method was developed that quantified insoluble and soluble fiber (AOAC 991.43; see Figure 1.2).

Again, it is an enzymatic/gravimetric method, using similar enzymes to digest carbohydrates and proteins. The viscous soluble fibers (higher

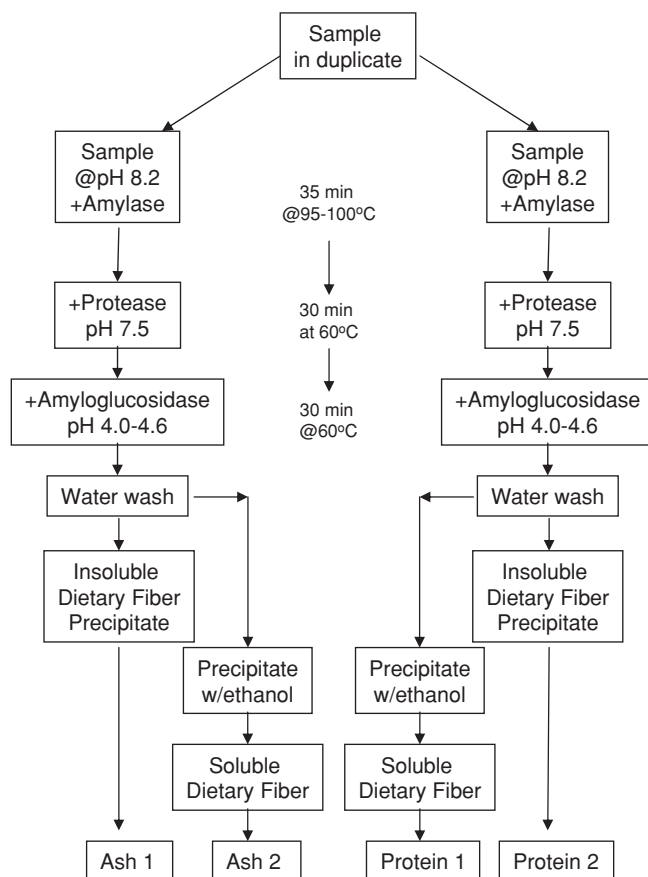
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Table 1.2. AOAC methods for fiber analysis.

AOAC method	Analyzes	
985.29	Total dietary fiber	Enzymatic/gravimetric
991.43	Insoluble and soluble fiber	Enzymatic/gravimetric
997.08	Fructans	Water extraction/enzyme/LC analysis/high performance anion-exchange chromatography with pulsed amperometric detection (HPEAD-PAD)
2001.03	Dietary fiber with resistant maltodextrin	Enzymatic/gravimetric/LC specific for resistant maltodextrin
2000.11	Polydextrose	Water extraction/enzyme /LC analysis HPAED-PAD
2001.02	Transgalactooligosaccharides	Water extraction/enzyme/LC analysis HPAED-PAD
2002.02	Resistant starch	Enzyme/glucose oxidase-peroxidase/ spectrophotometric
2009.01	Total dietary fiber (high molecular weight + low molecular weight)	Enzymatic/gravimetric /LC

molecular weight) are precipitated with ethanol and acetone, but unfortunately lower molecular weight moieties such as inulin and resistant maltodextrin are not analyzed with this method because they are soluble in ethanol. There has been some debate over exactly what molecular weight of fiber will precipitate with ethanol or acetone fraction and what will stay in solution. Some researchers feel that a degree of polymerization (DP) of 10 is the cutoff point, meaning that all fibers with a DP of over 10 will precipitate and those under 10 will stay in solution. The authors of this chapter are of the opinion that the molecular structures of particular nondigestible carbohydrate dictate what precipitates and what does not and that the DP of what does or does not precipitate in this method can be variable, depending on molecular structure. Branching and bonding as well as monosaccharide composition of nondigestible low molecular weight carbohydrates influences solubility in both water

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$$\text{Total Dietary Fiber} = (\text{IDF} - \text{Ash 1} - \text{Protein 1}) + (\text{SDF} - \text{Ash 2} - \text{Protein 2})$$

Figure 1.2. AOAC method 991.43: enzymatic/gravimetric method for fiber analysis.

and alcohol. It is not the purpose of this chapter to debate on this issue, simply to bring it to light and let the reader form his or her own opinion in this matter.

Evidence for the health benefits of lower molecular weight soluble fibers and other nondigestible carbohydrates as fermentable substrates started to develop in the late 1980s and early 1990s. An often-quoted review paper by Gibson and Roberfroid (1995) proposed a definition of prebiotic stating, “A prebiotic is a nondigestible food ingredient that beneficially affects the host by selectively stimulating the growth and/or activity of one or a limited number of bacteria in the colon, and

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thus improves host health.” Later criteria were added for resistance to digestion, expanding the 1995 definition (Roberfroid 2009).

Roberfroid (2009) recently summarized the state of the science detailing functional effects and disease risk reduction, with functional effects such as intestinal colonic function, bioavailability of minerals, and satiety and disease risk reduction such as metabolic syndrome, obesity, and colon cancer in the book *Handbook of Prebiotics* (2009). Other authors in this book go into much greater detail regarding health benefits and mechanisms of lower molecular weight nondigestible carbohydrates. As evidence mounted for fermentability and/or prebiotic nature of lower molecular weight nondigestible carbohydrates and was amassed, more AOAC methods were created to analyze the components separately, using liquid chromatography and some spectrophotometric methods. The evolution of fiber analysis in Table 1.2 shows the complexity of analyzing for constituents such as inulin or polydextrose and the variety of methods used to do so.

Of particular note here is resistant starch. Other authors in this book detail the types and physiological functions in much greater detail but from an analytical viewpoint, it is not quite insoluble or soluble fiber and the quantity can be misrepresented by traditional fiber analysis methods. Both the 985.29 and 991.43 AOAC methods digest substrates at a temperature of 100°C for 30 minutes using nonmammalian enzymes, conditions that do not reflect human digestion. Type 2 and 3 resistant starches are either naturally inherent crystalline material (type 2) or created by retrogradation (type 3), may be subject to partial gelatinization and solubilization in solution at the high temperature, and can be lost in the analysis. AOAC 985.29 and 991.43 fiber analytical methods are standardized and do provide a good estimation of fiber for a wide range of food products, but it was clear that better methods needed to be developed and was the subject of great debate at both AACC and International Food Technologists (IFT) meetings for a number of years.

Recently, a new definition of fiber was put forth by the Food and Agriculture Organization (FAO) and the World Health Organization at the Codex Alimentarius Commission during the 32nd session at FAO Headquarters, Rome, June 29–July 4, 2009 (ALINORM 09/32/A) as detailed in Table 1.1. Accompanying the new definition, an analysis was developed by Barry McCleary (in collaboration with others) recently as AOAC 2009.01 method issued late in 2009. A summary of this method is shown in Figure 1.3.

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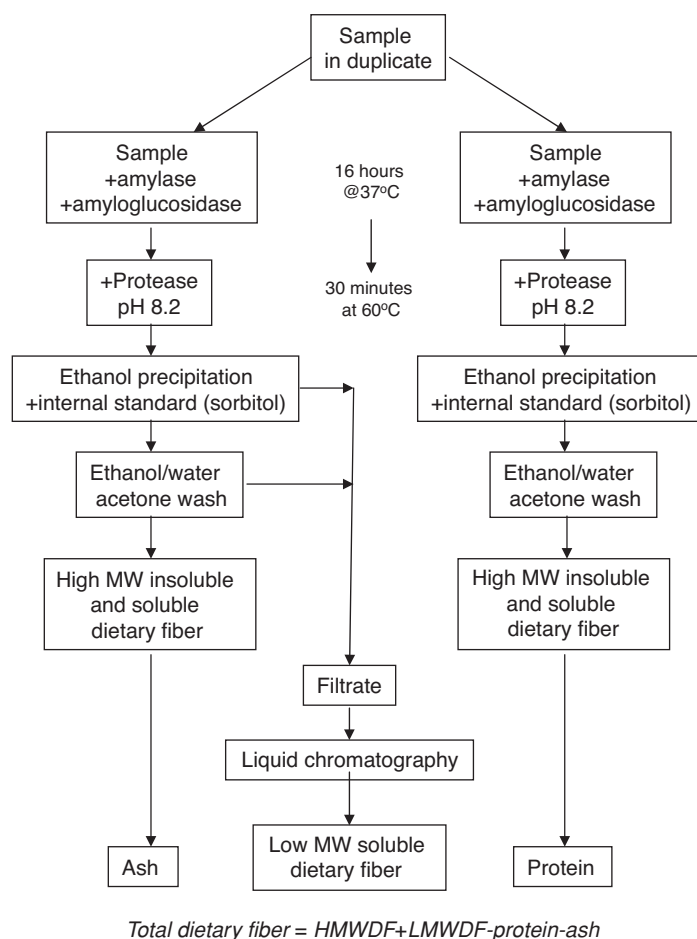


Figure 1.3. AOAC method 2009.01: enzymatic/gravimetric method for fiber analysis.

This method more closely reflects human carbohydrate digestion by providing a 16-hour digestion for the starch portion of digestible carbohydrate at 37°C, rather than 30 minutes at 100°C as per the 985.29 and 991.43 earlier methods. AOAC 2009.01 also uses a porcine pancreatic amylase, rather than the fungal-derived heat stable amylase in 985.29 and 991.43, again closer to mammalian digestion. Undoubtedly, this is an improvement over previous methods, although this method will only report high molecular weight fiber and low molecular weight fiber and does not separate out the soluble viscous portion as does 991.43. As

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this method gains acceptance and adoption by the food industry, we can hope to see more consistent and less confusing results when it comes to testing for fiber. Although AOAC 2009.01 more closely reflects mammalian digestion, it is still wise to note that it is an analytic method (as are AOAC 985.29 and 991.43) meant to mimic (and thus is not an exact replicate of) digestion and fermentation. Care must be taken not to interpret results as completely accurate representation of mammalian digestion. Official AOAC methods are meant to standardize an analysis, making it easy to replicate as cheaply as possible. To understand true digestion and fermentation, researchers must use animal or human data.

A problematic issue with fiber fermentation research and in vitro methods is how to prepare samples. Substrates such as resistant starch, oligosaccharides (with residual sugars from manufacturing), brans, and legumes have components that are completely digestible in the upper gastrointestinal tract.

Digestible starch and sugars can give misleading results as they are readily available for microbial fermentation. Some researchers attempt to predigest substrates with various procedures to simulate digestions, some of which are based on the AOAC methods because they are standardized and kits are easily obtained. Some researchers (especially in earlier work) do not predigest samples. This variable alone can cause significantly different results between researchers when studying the same substrates. When the variability of individual animal or human fecal flora is compounded by inadequate or erroneously digested samples using in vitro methods, comparing data between research studies is impractical. Again, use of fiber analysis methods or variations for predigestion is best used as an approximation of digestion, with full knowledge of the flaws of these methods.

As is shown in Tables 1.1 and 1.2, the analytical methods for fiber reflect developments in the discovery of health benefits associated fiber and nondigestible carbohydrates and our ability to identify the components responsible for the effect.

These will change in the future as more research is published regarding the health benefits of nondigestible carbohydrates and fiber. In coming years, the editors of this book hope that these issues are resolved to the extent they can be and it is important to remember the ultimate goal for all concerned is to improve public health. In the mean time, it is hoped that the reader realizes the definitions and health benefits of nondigestible carbohydrates and/or fiber are an emerging science that

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will continue to evolve over time and that a certain amount of debate is to be both welcomed and expected.

It is very well-established fact that people do not eat enough fiber and nondigestible carbohydrates globally. Increasing the body of research regarding the science surrounding the health benefits of these substances enables the development of more consumer-friendly forms that will encourage fiber consumption.

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