Classification and methodology of food carbohydrates as related to nutritional effects

Nils-Georg L Asp

ABSTRACT  Dietary guidelines encourage a considerable increase in carbohydrate intake compared with the present situation in Western countries. Recent developments regarding nutritional effects of various digestible and undigestible carbohydrates call for more detailed recommendations. The "carbohydrate by difference" concept emerged 150 y ago because of the lack of specific analytical techniques and still prevails. The concept of available compared with unavailable carbohydrates was introduced in 1929 to obtain a better measure of glucogenic carbohydrates in diabetes. Dietary fiber was first defined as the "skeletal remnants of plant cell walls," but the definition was later expanded to include all polysaccharides and lignin that are not digested in the small intestine. The gravimetric method of the Association of Official Analytical Chemists for total dietary fiber is based on this undigestibility concept. However, precipitation of soluble fiber components with alcohol, which is used in all current methods, creates an arbitrary delimitation between oligo- and polysaccharides. The complex carbohydrates concept is challenged by recent developments regarding nutritional effects of various food carbohydrates.  Am J Clin Nutr 1995;61(suppl):930S–7S.

KEY WORDS  Dietary guidelines, simple sugars, complex carbohydrates, disaccharides, oligosaccharides, polysaccharides, starch, dietary fiber, inulin, polyols

Introduction

Until recently, recommendations on carbohydrate intake have been more or less secondary to guidelines regarding protein and fat intakes. The dietary fiber hypothesis, however, focused attention on the undigestible carbohydrates that are also in the human diet. Consequently, many dietary guidelines now include recommended daily intake of dietary fiber (1).

It has generally been assumed for a long time that sugar and other low-molecular-weight carbohydrates are more rapidly digested and absorbed in the small intestine than is starch, the only digestible food polysaccharide. This assumption forms a main part of the concept of "complex carbohydrates" (2). As summarized below, several food-related factors other than the molecular size of the carbohydrates are now known to determine glycemic and hormonal responses after intake of carbohydrate. The glycemic index of foods is important in diabetes (3) and may be related to blood lipid concentrations, blood pressure, satiety, and physical performance (4).

Sucrose has been implicated as the arch criminal in dental caries and there is much evidence that sucrose intake is closely related to caries. However, dental health has improved in many countries despite a continuous sucrose intake above the recommended amount. Host resistance factors, including general nutritional status, obviously modulate the effect of sucrose, leaving certain groups at risk (5). Furthermore, other fermentable carbohydrates, including starch, are capable of lowering dental plaque pH after a meal and thus are potentially cariogenic (6, 7).

Historical aspects

The proximate analysis of foods and feed developed in the middle of the 19th century. Because of the absence of specific analytical techniques carbohydrates were considered to be the material remaining after analysis of protein, fat, ash, and moisture (8). Studies of ruminant nutrition at the Weende Experimental Station in Germany revealed differences in the feed value of different carbohydrates and this led to the concept and analysis of crude fiber (9).

In a recent review, Southgate (10) described further developments regarding carbohydrates. Atwater (11) realized that foods containing significant amounts of crude fiber had lower digestible energy than predicted by measuring "carbohydrates by difference." This led to the introduction, in due time, of the specific energy conversion factors of Merrill and Watt (12). The first to report more detailed analytical work on carbohydrates in food was Rubner (13) in 1917. He used hydrolysis and reducing sugar methods and also measured lignin as the acid-insoluble residue.

A milestone in the understanding of the nutritional importance of food carbohydrates was the differentiation of "available" and "unavailable" carbohydrates by McCance and Lawrence (14) in 1929. Their main objective was to define glucogenic (available) carbohydrates to improve nutritional counseling to diabetic subjects. These authors also considered the question, far ahead of their time, of whether short-chain fatty acids that were produced as the result of fermentation of unavailable carbohydrates would provide any energy to the body. In 1935 Widdowson and McCance (15) developed methods for analyzing reducing sugars, sucrose, and starch in foods

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as a measure of available carbohydrates, which were subsequently introduced in British food tables (16). In the United States, Williams and Olmstedt (17) developed a method in 1935 that simulated digestion by incubating a food sample with pepsin and pancreatin. The residue provided a more physiological way to estimate undigestible material than the acid and alkali treatment used in the crude fiber method. In fact, this work was the basis for enzymatic gravimetric methods for dietary fiber analysis, which were developed later by Hellen-doorne et al. (18) in the Netherlands. The introduction of colorimetric methods that were group-specific (i.e., for pentoses, hexoses, and uronic acids) constitutes the next step in analytical developments. Such methods form the basis for Southgate’s analytical scheme including both digestible (available) and undigestible (unavailable) carbohydrates (19, 20). In the 1960s, Van Soest and Wine (21, 22) provided important contributions toward improvement of the crude fiber method of animal nutrition, leading to the acid detergent and neutral detergent fiber methods and subsequently to modifications suitable for starchy foods (23, 24). In Berlin, Thomas (25) studied both chemical and physiological aspects of “Ballaststoffen” in cereal flours and bran.

The term “dietary fiber” was first used by Hipsley (26) in 1953 to describe plant cell walls in the diet, which he thought were protective against toxemia of pregnancy. In 1972, Trowell (27) detected differences in the incidence of noninfective diseases in rural Africa and Western countries and defined dietary fiber as “the skeletal remains of plant cells,” later rephrased to “remnants of the plant cell wall” (28). In 1976, the definition was extended to include all undigestible polysaccharides and lignin (29). Two factors led to this new definition: first, isolated polysaccharides such as pectin and guar gum were used to study physiological effects of dietary fiber components, and second, such isolated polysaccharides, which were often used as food additives, could not be differentiated analytically from plant cell wall polysaccharides (30). In fact, knowledge about effects of dietary fiber on carbohydrate and lipid metabolism is still based mainly on studies with isolated polysaccharides (31, 32). These have often been used in amounts far exceeding those occurring naturally in foods and the effects extrapolated to foods. To date, no physiological effects of dietary fiber components per se have been attributed to their presence in the plant cell wall; rather, the consequences of dietary fiber components are attributed to their undigestibility and to their physical properties such as viscosity (33). The presence of cells with intact walls composed of fiber polysaccharides is important for the enclosure of nutrients such as sugars in fruits (34) and starch in beans (35, 36), slowing their absorption.

As described by Southgate (37), the 1976 definition of dietary fiber of Trowell et al (29) is virtually identical with that for unavailable carbohydrates (14). This definition could include the recently discovered resistant starch (38), and has been widely accepted throughout the world by both scientists and policymakers.

**Primary carbohydrates of food**

The most important properties of the primary carbohydrates of food (Table 1) that influence nutritional value include the following: the extent of absorption in the small intestine, the rate of absorption in the small intestine, the metabolism of absorbed monomers, and the extent, rate, and nature of products of fermentation in the large intestine. The extent of digestion in the small intestine (digestibility) determines how large the fraction of total carbohydrates is that will provide glucose to the organism and the amount of carbohydrate that will pass to the large bowel for subsequent fermentation. The digestibility of food carbohydrates is the most important nutritional property. The rate of absorption in the small intestine primarily determines the glycemic and hormonal responses after a meal and is often expressed as the glycemic index, as defined by Jenkins et al (39).

Glucose and fructose, which are present in foods as free sugars or constituents of sucrose, are metabolized differently; fructose yields much lower postprandial glycemic and insulin responses than does glucose. Accordingly, the ratio of glucose to fructose in the diet is of clinical interest, especially in diabetes (40). Fermentation of undigestible carbohydrates is now the subject of much interest and research. There is evidence, mainly from in vitro studies, that the proportion of the various short-chain fatty acids formed during fermentation differs depending on the specific carbohydrate as substrate, with concomitant differences in physiological effects (41).

**Mono- and disaccharides**

The free monosaccharides (glucose and fructose) are present in fruits, berries, and vegetables. Accordingly, intake of these sugars may be considerable in a vegetarian diet (42). Free galactose is present in a very small amount, except in fermented milk products, as a result of the preference of microorganisms for glucose during fermentation (43). Sucrose is usually the most abundant disaccharide in both mixed and vegetarian diets (42). The lactose intake stems from milk

<table>
<thead>
<tr>
<th>TABLE I</th>
<th>Main food carbohydrates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monosaccharides</td>
<td>Glucose</td>
</tr>
<tr>
<td>Fructose</td>
<td>Disaccharides</td>
</tr>
<tr>
<td>Sucrose</td>
<td>Lactose</td>
</tr>
<tr>
<td>Oligosaccharides</td>
<td>α-Galactosides</td>
</tr>
<tr>
<td>Raffinose, stachyose</td>
<td>Fructans</td>
</tr>
<tr>
<td>Fructooligosaccharides</td>
<td>Polysaccharides$^*$</td>
</tr>
<tr>
<td>Starch</td>
<td>Amylose</td>
</tr>
<tr>
<td>Amylopectin</td>
<td>Modified food starches</td>
</tr>
<tr>
<td>Nonstarch polysaccharides</td>
<td>Cellulose</td>
</tr>
<tr>
<td>Hemicellulose</td>
<td>Pectins</td>
</tr>
<tr>
<td>β-glucans</td>
<td>Fructans</td>
</tr>
<tr>
<td>Gums</td>
<td>Mucilages</td>
</tr>
<tr>
<td>Algal polysaccharides</td>
<td></td>
</tr>
</tbody>
</table>

$^*$Degree of polymerization > 10–20.
products, with cow milk containing ~50 g/L. The absorption capacity for mono- and disaccharides is high, except in individuals with disaccharidase deficiencies. However, recent studies have demonstrated a limited absorption capacity for fructose when it is given alone. Simultaneous intake of glucose increases the absorption of fructose (44, 45).

**Oligosaccharides**

The quantitatively most important oligosaccharides are the α-galactosides raffinose, stachyose, and verbascose, which have three, four, and five monomeric units, respectively, and the fructooligosaccharides (45). The α-galactoside content is 5–8% on a dry matter basis in beans, lentils, and peas. Fructooligosaccharides and higher molecular weight fructans constitute up to 60–70% of the dry matter in some plant tissues (e.g., Jerusalem artichokes and onions), and fructooligosaccharides are found in smaller amounts in many plants, including cereal grains (46). The α-galactosides are not hydrolyzed by human intestinal enzymes (47). An increased use of both fructooligosaccharides and fructans and other undigestible oligosaccharide preparations can be expected in foods because of their reduced energy content, their effects on the intestinal flora, and their functional properties (48).

**Polyols and polydextrose**

Small amounts of sugar alcohols (polyols) such as sorbitol are found in fruits. There is an increasing use of polyols such as xylitol, sorbitol, mannitol, lactitol, and maltitol as low-energy and noncariogenic bulk sweeteners (48). There is a limited capacity of the small intestine to absorb these sugar alcohols (49).

Polydextrose, a synthetic glucose polymer that is used as a low-energy bulking agent, is undigestible because of glycosidic linkages that are essentially resistant to amylase (50).

**Starch**

Starch is the most important food carbohydrate quantitatively and together with glycogen is the only digestible food polysaccharide. It occurs as a mixture of virtually unbranched amylose chains composed of α-1,4-linked glucose residues and of highly branched amylopectin with α-1,4 and α-1,6 bonds. Chemically modified food starches in which ester or ether groups have been introduced are used as food additives.

The generally accepted concept that starch is completely although slowly digestible has been challenged recently. Hydrolysis of starch is initiated by salivary amylase and is completed in the small intestine. In 1961 it was demonstrated that amylase activity in the duodenum is sufficient to hydrolyze starch in a meal within minutes (51). Consequently, starch in solution, partially degraded starch, and glucose give the same glycemic and insulin responses when given in equivalent amounts (52). However, the glycemic index of starchy foods varies widely (53) because of food properties affecting the availability of starch for enzymatic degradation (54). Resistant starch was first discovered as a starch fraction that associated with the nonstarch polysaccharides in dietary fiber analyses unless the sample had first been treated with alkali or dimethylsulfoxide (DMSO) to solubilize this starch (55, 56). However, this type of resistant starch, identified as retrograded amylose (57, 58), is only one of several forms of physiologically resistant starch that pass through the small intestine (59).

Physically enclosed starch in beans, for example (60), and ungelatinized starch granules of the B-type (e.g., green bananas and raw potato starch) are other forms of resistant starch, as well as chemically modified (61) or dry-heated (62) food starches. The physiological effects of resistant starch are currently being investigated. Resistant starch is fermented (63) and has a fecal bulking effect (64, 65), representing properties that are considered to be typical for nonstarch polysaccharides.

**Nonstarch polysaccharides**

Nonstarch polysaccharides can be storage polysaccharides such as fructans (e.g., inulin), glucomannans, and galactomannans (e.g., guar gum), although structural plant cell wall polysaccharides such as cellulose, hemicellulose, and pectic substances are the most abundant. Mucilages, alginates, exudate gums, and various modified polysaccharides are other constituents of the nonstarch polysaccharides (30). The fecal bulking effect of dietary fiber is most prominent if the nonstarch polysaccharides are resistant to fermentation in the large intestine (66, 67). Other physiological effects, such as lowering of plasma low-density-lipoprotein (LDL) cholesterol and attenuation of blood glucose and insulin responses after a meal, are attributed mainly to soluble, gel-forming polysaccharides. However, the LDL-lowering properties of dietary fiber in foods are modest and the fact that high-fiber foods are generally low in saturated fat may be more important in clinical practice (31). Similarly, the content of viscous, soluble fiber, such as β-glucans in cereals, is less important for the glycemic response than are structural properties that limit the availability of starch for enzymatic degradation (68, 69). An effect of carrots on reducing the glycemic response after a mixed meal is seen only if ≥200 g carrots are added to the meal (70, 71). Thus, excessive emphasis on the soluble fiber content of foods may be misleading and the physiological properties of the soluble fiber may be lost if viscosity is diminished through processing (33).

**Analytical considerations**

**Mono-, di-, and oligosaccharides, including polyols**

Depending on the food matrix to be analyzed, an alcohol extraction of the free sugars may be necessary. A final ethanol concentration of ≥80% (vol:vol) should be used to avoid extraction of polysaccharides. Some sugars, especially lactose, have low solubility and may need lower alcohol concentrations (e.g., 50% vol:vol) during extraction with a final increase to precipitate polysaccharides (72). Physical methods such as polarimetry, refractive index, or density are still useful in pure systems, such as in sugar production control. Methods based on the reduction of copper salts and colorimetric methods based on condensation reactions with anthrone, orcinol, and carbasol can also be used in well-known systems (72). The enzymatic procedures based on specific, highly purified enzymes (73) have been instrumental in providing means of specific and precise analysis of carbohydrates in mixtures without high-capital investments. On the other hand, gas-liquid chromatography and HPLC are preferable when several different carbohydrates are to be determined simultaneously. HPLC analysis has been hampered by the relative insensitivity of refractory
index detectors. However, this problem has been overcome by systems using amperometric detection (74).

**Starch**

Enzymatic hydrolysis and specific glucose assay are the methods of choice for the measurement of starch. Acid hydrolysis is less suitable in mixed foods because of glucose liberation from other glucose-containing polysaccharides such as β-glucans. However, the enzymes used have to be carefully monitored for contaminating activities. A heat-stable amylase such as Termamyl in a combined gelatinization and hydrolysis step has turned out to be particularly useful (75).

**Dietary fiber**

There has been extensive controversy regarding the analysis of dietary fiber, partly because the needs for research have not been clearly separated from those of food labeling and legislation. Dietary fiber can be analyzed according to two main yet different principles (30). In the gravimetric methods the nonfiber components are removed and the residue is weighed. This residue can be analyzed for monomeric composition or starch residues and also for protein and ash. The crude fiber and detergent fiber methods are both gravimetric methods. Enzymatic gravimetric methods as developed by Asp et al (76) and approved by the Association of Official Analytical Chemists (AOAC) (77, 78) use alcohol precipitation to recover soluble fiber components. Such methods are useful to measure total dietary fiber or soluble and insoluble components separately, with appropriate correction for protein and ash in the fiber residue. The component analysis methods use more or less specific determination of monomeric constituents, with subsequent summing up for a total fiber determination. As in the gravimetric methods, soluble and insoluble components can be determined separately. However, the solubility of polysaccharides is method-dependent and is determined by temperature, time, and pH (79). The Southgate procedure (19) uses colorimetric methods to determine hexoses, pentoses, and uronic acids. The methods of Theander et al (80) and Englyst et al (81) use gas-liquid chromatography for neutral sugar components and a colorimetric assay for uronic acids. HPLC determination is gaining in popularity. A colorimetric measurement of reducing sugars has been introduced as an alternative to the gas-liquid determination method developed by Englyst et al (81).

Advantages and disadvantages with the two principally different methods of analyzing dietary fiber are summarized in Table 2. Enzymatic-gravimetric methods are simple and robust, with no requirement for advanced equipment. There is a risk of overestimating the fiber content if other components remain in the residue. However, the residue can be analyzed for any such contaminating components. Colorimetric methods can be inflated by nonspecific reactions and can give various response factors for different monomers. Specific gas-liquid chromatography and HPLC measurement, on the other hand, require complete and quantitative recovery of monomers after hydrolysis of the polysaccharides. Incomplete hydrolysis or losses due to decomposition of monomers will lead to underestimation (30).

The current component analysis methods use acid hydrolysis. As in amino acid analysis, conditions for hydrolysis have to be chosen to obtain an optimal compromise between hydrolysis yield and monomer degradation. Corrections are used for hydrolysis losses of the different components. Quantitative hydrolysis is particularly difficult to obtain with acidic polysaccharides because of the high acid stability of glycosyl uronic acid linkages. This fact and the more rapid degradation of monomeric uronic acids in an acidic condition are reasons why colorimetric methods are still preferred for uronic acid determinations (30).

Enzymatic, gravimetric dietary fiber determination has been tested in several collaborative studies carried out within the AOAC. Recently this organization also tested the gas-liquid chromatography component analysis method of Theander et al (80). The gas-liquid chromatography and colorimetric varieties of the Englyst method have been tested in studies carried out by the Ministry of Agriculture, Food and Fisheries in Great Britain. A comparison of studies indicates improved performance over time with typical mean RSD values of 2–3 for both the gravimetric methods approved by the AOAC and for the Englyst method. The best performance thus far has been in a Swiss study using the enzymatic gravimetric AOAC method (RSD, 1.0–1.1) (82). An RSD of 2 at 100 g dietary fiber/kg means that 19 of 20 single estimates run in different laboratories are likely to fall within the interval of 90–110 g/kg.

There are few formal collaborative studies covering more than one method. In a recent study coordinated by the European Community Bureau of Reference, dietary fiber values with the AOAC method could be certified for three different materials. Indicative values only could be given for the Englyst gas-liquid chromatography and colorimetric methods, but mean values obtained with these methods were similar to those obtained with the AOAC method (83). For most foods, estimates of total dietary fiber with the enzymatic gravimetric method would not be significantly different from estimates of nonstarch polysaccharides derived from the Englyst method. This means that the CIs for the different methods overlap (30). Note also that two collaborative studies have shown consistently higher values with the colorimetric Englyst method than with the original gas-liquid chromatography variety (30). Only for foods with particularly high amounts of resistant starch of the retrograded amylose type, or lignin, would Englyst-derived values be expected to be significantly lower than estimates with methods including these components.

**Resistant starch**

Methods for analysis of resistant starch are listed in Table 3. Originally, resistant starch was determined as the difference in

### Table 2

<table>
<thead>
<tr>
<th>Component Analysis</th>
<th>Enzymatic-gravimetric</th>
<th>Component Analysis</th>
<th>GLC, HPLC</th>
<th>Colorimetric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>Simple</td>
<td>Advanced</td>
<td>Simple</td>
<td></td>
</tr>
<tr>
<td>Information on composition</td>
<td>No</td>
<td>Advanced</td>
<td>Yes and no</td>
<td>(Yes)</td>
</tr>
<tr>
<td>Risk of overestimation</td>
<td>Yes³</td>
<td>No</td>
<td>(Yes)</td>
<td></td>
</tr>
<tr>
<td>Risk of underestimation</td>
<td>No</td>
<td>Yes¹</td>
<td>Yes¹</td>
<td></td>
</tr>
</tbody>
</table>

¹ For review, see reference 30. GLC, gas-liquid chromatography; HPLC, high-pressure liquid chromatography.
² Residue can be analyzed.
³ If hydrolysis is incomplete.
TABLE 3
Methods for analysis of resistant starch

<table>
<thead>
<tr>
<th>Year</th>
<th>Principle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1982</td>
<td>Difference between NSP glucan with and without DMSO or KOH solubilization (55)</td>
</tr>
<tr>
<td>1984</td>
<td>Starch analysis in dietary fiber residue (56)</td>
</tr>
<tr>
<td>1986</td>
<td>Extensive α-amylase digestion, analysis of remaining starch, and no gelatinization step (84)</td>
</tr>
<tr>
<td>1992</td>
<td>Standardized ball milling and amylase digestion, and analysis of various resistant starch fractions (85)</td>
</tr>
<tr>
<td>1992</td>
<td>Chewing to disintegrate foods, pepsin and pancreatin digestion, analysis of remaining starch (86)</td>
</tr>
</tbody>
</table>

NSP, nonstarch polysaccharide; DMSO, dimethylsulfoxide.

nonstarch-polysaccharide-glucan without and with DMSO solubilization (55), or by analyzing a gravimetric fiber residue for starch associated with the fiber (56, 87). This starch can be differentiated into “residual starch” or “resistant starch” (87). The resistant starch determined by these methods consists of mainly retrograded amylose (57, 58). Berry developed a method in which the sample was subjected to extensive α-amylase digestion without any heating step to gelatinize the starch. In this way, resistant starch in the form of intact starch granules would also be analyzed. Two methods have been published that are proposed to measure all of the physiologically resistant starch (85, 86). A critical step is then to disintegrate the food in a similar manner as when eaten. One of these procedures uses chewing as a realistic disintegration step (86), whereas the other method uses a standardized ball-milling step (85). Both methods correlate with in vivo resistant starch as measured in subjects with ileostomies.

Dietary fiber and unavailable carbohydrates

The definition of dietary fiber as undigestible polysaccharides and lignin is similar to the definition of “unavailable carbohydrates,” which is based on the fundamentally different nutritional importance of various carbohydrates as determined by their digestibility in the small intestine. Discussions of the definition and analysis of dietary fiber have focused on whether resistant starch and lignin are included (88, 38). Equally important, however, is awareness of components that are not precipitated in the 70–80% (vol:vol) ethanol used in all the methods to separate water-soluble fiber components. Inulin is an undigestible polysaccharide that is not precipitated and therefore not recovered in any of the methods. Polydextrose is another undigestible oligopolysaccharide that also is not determined as dietary fiber. Physiologically, undigestible oligosaccharides have much in common with nonstarch polysaccharides; they are fermented and influence the bacterial flora of the colon (48, 89). Specific enzymatic or HPLC methods must be used to determine the undigestible oligo- and polysaccharides not recovered in the current dietary fiber analyses.

Classification of food carbohydrates for nutrition labeling

Ever since the introduction of the carbohydrate by difference concept, it has been customary in most countries to label both digestible carbohydrates and dietary fiber as carbohydrates. Chemically this is obviously correct and this convention has been kept in the recent implementation of the US Nutrition Labeling and Education Act (90). The Commission of the European Communities, on the other hand, has defined carbohydrates as metabolizable carbohydrates including polyols (91). “Metabolizable” obviously means that carbohydrates must be digestible in the small intestine, and this definition, therefore, is related to the available carbohydrates concept (14). Dietary fiber remains to be defined by the Commission.

The unavailable carbohydrates concept preceded the dietary fiber concept, which was also based on undigestibility in the small intestine. The plant cell wall origin of dietary fiber was emphasized in the epidemiological association between dietary fiber intake and disease. Physiological effects of dietary fiber, however, have been related to undigestibility and physical effects of dietary fiber constituents in the intestinal tract but never to their plant cell wall origin. The importance of cell walls in legumes and fruits for the glycemic response of these foods is recognized, but disruption of these structures without removing the fiber will abolish these effects. Methods pretending to give an index of plant cell walls cannot reveal such structural properties (81).

A classification of food carbohydrates for nutritional labeling should be based on small intestinal digestibility. The enzymatic gravimetric AOAC methods for total fiber (77, 78) or the component analysis method of Theander et al (80), which include one important form of resistant starch and lignin, give a closer measurement of unavailable carbohydrates than do the Englyst methods (81), which do not include resistant starch and lignin. However, all the methods including resistant starch need further development regarding the distinction between digestible and resistant starch. Furthermore, separate estimates of alcohol-soluble but undigestible components, such as inulin, polydextrose, and oligosaccharides have to be performed when such components are present in significant amounts. The relation between nonstarch polysaccharides, total dietary fiber according to the AOAC method, and unavailable carbohydrates is illustrated in Figure 1.

When a dietary fiber definition and an estimate as close as possible to unavailable carbohydrates are used, available or

![Figure 1](image-url)
metabolizable carbohydrates can be calculated by difference. Accordingly, an estimate of dietary fiber can be obtained by difference if mono- and disaccharides and digestible starch are determined as originally advised for unavailable carbohydrates (15).

The labeling of soluble fiber according to the AOAC method is mandatory in the United States if claims regarding cholesterol-lowering effects of the fiber are to be made. This requirement is reasonable because the cholesterol-reducing effects are specifically related to gel-forming, soluble types of fiber. Note, however, that the solubility of dietary fiber polysaccharides is highly method-dependent because of different extraction conditions (79). The most relevant conditions, from a physiological perspective, remain to be defined. The monomeric composition of dietary fiber is of little guidance to predict physiological effects, which are more related to viscosity, fermentability, and structural properties of foods. However, standardized methods for measuring such properties are still lacking, although in vitro systems for prediction of glycemic response seem promising (92). Such methods may prove useful for documentation of food properties as a basis for specific dietary advice or claims, although they may not be suitable to produce specific data appropriate for food labels.

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