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Dietary Fiber: Chemical and Functional Properties

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Abstract

Dietary fiber is a ubiquitous component of plant foods including materials of diverse chemical and morphological structure.

Dietary fiber has been recognized to have considerable health benefits, and there is evidence that a low intake may be associated with a number of diseases.

Dietary fiber is a polymer matrix with variable physicochemical properties including susceptibility to bacterial fermentation, water-holding capacity, cation-exchange, and adsorptive functions. These properties determine the physiological actions. Fiber undergoes compositional changes as a consequence of bacterial enzymatic action in the colon. Dietary fiber is of clinical significance in certain disorders of colonic function and in glucose and lipid metabolism.

Determination of the physical and chemical properties of fiber and the evolution of these properties during passage along the gastrointestinal tract is of great importance for the prediction of the role and influence of various types of dietary fiber has on human health.

Keywords: dietary fiber, oligosaccharides, polysaccharides, lignin

1. Introduction

Dietary fiber is a ubiquitous component of plant foods and includes materials of diverse chemical and morphological structure, resistant to the action of human alimentary enzymes but that may be digested by microflora in the gut. Source of dietary fiber include vegetables, wheat and most other grains. Foods rich in soluble fiber include fruits, oats, barley and beans.

The beneficial effects of dietary fiber have been known since ancient times, but became more clearly understood only between the 1950s and 1970s [1,2,3].

Ancient Greek physician Hippocrates, who famously said, "let food be thy medicine, and medicine be thy food," is known to have recommended the positive effects of whole-grain bread in the bowel.

Dietary fiber has been recognized to have considerable health benefits.

Extensive research has been carried out into the physiological effects of dietary fiber and there is evidence that a low intake may be associated with a number of diseases. Within the gastrointestinal tracts, fiber forms a matrix with both fibrous and amorphous characteristics.

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The physicochemical properties of this matrix determine the homeostatic and therapeutic functions of dietary fiber in human nutrition.

It is the purpose of this review to give an overview of important oligosaccharides and polysaccharides that function as dietary fiber, to discuss their occurrence and structures and their various physiological effects and health implications.

Definition of Dietary Fiber. Over the years dietary fiber has been defined in a variety of ways. The variations in the definitions were due partly to the multiplicity of concepts involved in "dietary fiber", and partly to the difficulties associated with its measurement and labeling.

In 1923 Kellogg and others stimulated the study of dietary fiber in the U.S.A. [4]; however the term "unavailable carbohydrate" was used long before [5].

It is generally believed that Hipsley was the first who used in 1953 "dietary fiber" as a shorthand term for the nondigestible constituents that make up the plant cell wall [6]. These constituents were cellulose, hemicellulose and lignin.

The term "dietary fiber" was clearly an attempt to distinguish some property or constituent of the food above and beyond what was then being measured by the crude fiber method [7].

Between 1972 and 1976, Trowell, Burkitt, Walker, Painter, and co-workers [8-13] used Hipsley's term to describe the remnants of plant components that are resistant to hydrolysis by human alimentary enzymes. These constituents were cellulose, hemicellulose, lignin and associated minor substances, such as waxes, cutin and suberin.

By 1976, the dietary fiber definition had been broadened to include all indigestible polysaccharides (mostly plant storage saccharides), such as gums, modified celluloses, mucilages, oligosaccharides, and pectins [14]. It remained primarily a physiological definition, identifying dietary fiber on the basis of resistance to digestion.

The physiological definition was reaffirmed among scientists internationally in surveys in 1992 [15] and 1993 [16] and as the outcome of a consensus workshop in 1995.

Dietary fiber includes many different substances; with the exception of lignin, all are carbohydrate in nature. Chemically fiber was defined as "non starch polysaccharides (NSP)" [17]. The NSP include cellulose and non-cellulosic polysaccharides (NCP) [18]. The latter includes: pectin and hemicelluloses (structural polysaccharides); fructans, glucofructans, mannans and galactomannan (storage polysaccharides); gums and mucilages (isolated polysaccharides), containing a mixture of pentoses, hexoses and uronic acids.

In the UK, the term dietary fiber has been replaced in nutrition labeling by non-starch polysaccharides [19,20].

The Constituents of Dietary Fiber. Dietary fiber includes all non-starch polysaccharides resistant to digestion in the small intestine and fermentable in the large intestine. Non-starch polysaccharides include celluloses, hemicelluloses such as arabinoxylans and arabinogalactans, pectins, modified celluloses, fructans (oligomers and polymers of fructose, i.e. inulin), gums, and mucilages. Oligosaccharides, such as oligofructans, include the lower molecular weight analogues of the digestion-resistant polysaccharides. Analogous carbohydrates, i.e. polysaccharides having the digestion resistance, fermentation and physiological properties of naturally sourced dietary fibers, are included. Lignin and the plants substances associated with the non-starch polysaccharides are an integral part of the fibrous portion of plants. Lignin, a polyfunctional polymer, is intimately formed with and infiltrates the cellulose of plant cell walls and is very resistant to digestion, even with strong acid. Likewise waxes and cutin, found as waxy layers at the surface of the cell walls, are made up of highly hydrophobic, long- chain hydroxy aliphatic fatty acids and are resistant to digestion and probably render the associated tissues resistant to digestion [21]. Suberin is hypothesized to be a highly branched and cross-linked combination of polyfunctional phenolics, polyfunctional hydroxyacids, and dicarboxylic acids [22] that are likely linked to the cell wall with ester linkages. Evidence of its intimate interaction with other dietary fiber components is the fact that only suberin-enriched fractions, but never purified suberin, have been prepared. Finally, phytate (phytic acid), tannins and saponins that are part of the dietary fiber complex are included. The constituents of dietary fiber are summarized in Table 1 [23].

Table 1. Constituents of Dietary Fiber

Fiber constituent	Principal groupings	Fiber components/sources
Non-starch polysaccharides and oligosaccharides	Cellulose	Cellulose-Plants (vegetables, sugar beet, various brans)
	Hemicellulose	Arabinogalactans, β-glucans, arabinoxylans, glucuronoxylans, xyloglucans, galactomannans, pectic substances
	Polyfructoses	Inulin, oligofructans
	Gums and Mucilages	Seed extracts (galactomannans – guar and locust bean gum), tree exudates (gum acacia, gum karaya, gum tragacanth), algal polysaccharides (alginates, agar, carrageenan), psyllium
	Pectins	Fruits, vegetables, legumes, potato, sugar beet
Carbohydrate analogues	Resistant starches and maltodextrins	Various plants, such as maize, pea, potato Polydextrose, lactulose, cellulose derivatives (MC, HPMC)
	Chemical synthesis Enzymatic synthesis	Neosugar or short chain fructooligosaccharides (FOS), transgalactooligosaccharides (TOS), levan, xanthan gum, oligofructose, xylooligosaccharides (XOS), guar hydrolisate, curdlan
Lignin	Lignin	Woody plants
Substances associated with non-starch polysaccharides	Waxes, cutin, Suberin	Plant fibers
Animal origin fibers	Chitin, chitosan, collagen, chondroitin	Fungi, yeasts, invertebrates

Table 2. Classification of fiber components based on fermentability

Characteristic	Fiber component	Main food source
Partial or low fermentation	Cellulose	Plants (vegetables, sugar beet, various brans)
	Hemicellulose	Cereal grains
	Lignin	Woody plants
	Cutin/suberin/other plant waxes	Plant fibers
	Chitin and chitosan, collagen	Fungi, yeasts, invertebrates
	Resistant starches	Plants (corn, potatoes, grains, legumes, bananas)
	Curdlan	Bacterial fermentation
Well fermented	β-Glucans	Grains (oat, barley, rye)
	Pectins	Fruits, vegetables, legumes, sugar beet, potato
	Gums	Leguminous seed plants (guar, locust bean), seaweed extracts (carrageenan, alginates), plant extracts (gum acacia, gum karaya, gum tragacanth), microbial gums (xanthan, gellan)
	Inulin	Chicory, Jerusalem artichoke, onions, wheat
	Oligosaccharides/analogues	Various plants and synthetically produced (polydextrose, resistant maltodextrin, fructooligosaccharides, galactooligosaccharides, lactulose)
	Animal origin	Chondroitin

The composition of fiber in the diet will depend on the age, species, and anatomical source of the plant material. Cellulose, the most abundant molecule in nature, is the beta isomer of starch; it is a long (up to 10,000 sugar residues) linear polymer of 1,4-β linked glucose units. Hydrogen bonding between sugar residues in adjacent chains imparts a crystalline microfibril structure. Cellulose is insoluble in most solvents including strong alkali [18].

Hemicelluloses are those cell wall polysaccharides solubilized by aqueous alkali after removal of water soluble and pectic polysaccharides. They contain backbones of β-(1,4)-1inked pyranoside sugars, but differ from cellulose in that they are smaller in size (often less than 200 sugar residues), contain a variety of sugars, and are usually branched [18].

The hemicelluloses are classified on the basis of the principal monomer sugar residue. Acidic or neutral forms differ in the content of glucuronic and galacturonic acids [24]. Uronic acid formation involves the oxidation of the terminal -CH_2OH to -COOH and is of biological importance since the sugar residues become available for methylation, amidation, and the formation of cation complexes [25]. Hemicelluloses, especially the hexose and uronic acid components, are somewhat more accessible to bacterial enzymes than is cellulose [26].

Pectic substances are a complex group of polysaccharides in which D-galacturonic acid is a principal constituent. They are structural components of plant cell walls and also act as intercellular cementing substances. Included are a water-insoluble parent compound, protopectin, as well as pectinic acids, pectic acids, and pectin. The backbone structure of pectin is an unbranched chain of axial-axial α-(1-4)-linked D-galacturonic acid units. Long chains of galacturonan are interrupted by blocks of L-rhamnose-rich units that result in bends in the molecule. Many pectins have neutral sugars covalently linked to them as side chains, mainly arabinose and galactose, and to a lesser extent, xylose, rhamnose, and glucose. The carboxyl groups of the galacturonic acids are partially methylated and the secondary hydroxyls may be acetylated. Pectin is highly water-soluble and is almost completely metabolized by colonic bacteria.

Nutritional and Health Effects. Consuming adequate quantities of dietary fiber can lead to improvements in gastrointestinal health, and reduction in susceptibility to diseases such as diverticular disease, heart disease, cancer and diabetes. Increased consumption has also been associated with increased satiety and weight loss. High fiber foods, because of their consistency, encourage mastication and stimulate the secretion of digestive juices.

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. Three physiological impacts characteristic of insufficient dietary fiber consumption have proven to be consistently present as a result of almost 50 years of research. These physiological impacts of insufficient dietary fiber intake are constipation, increased risk of coronary heart disease, and increased fluctuation of blood glucose and insulin levels.

Fiber intake through the consumption of foods rich in this dietary component, such as fresh vegetables, fruits, whole grains and nuts, is associated with reductions in plasma LDL-cholesterol, attenuating glycemic and insulin response, increasing stool bulk, and improving laxation [27]. Moreover, dietary fiber consumption reduces the risk of most of the major dietary problems: obesity, coronary disease, diabetes, gastrointestinal disorders, including constipation, inflammatory bowel diseases like diverticulitis and ulcerative colitis, and colon cancer [28]. Recent epidemiological data show that a diet high in fiber generally reflects a healthier life style [29] and fiber intake can be viewed as a marker of a healthy diet.

Despite the healthful influence dietary fiber can have on reducing the risk of chronic disease, the intake remains low in many populations worldwide. The gastrointestinal tract is the primary area of action of dietary fiber, most notably in the large intestine [30]. The physiological effects of dietary fiber depend on the type (partially fermentable or highly fermentable), the dose of a specific fiber consumed, the composition of the entire fiber-containing meal, and the individual physiological profile of the subject consuming the fiber-containing meal. The major physiological effects of dietary fiber originate from the interactions with colonic content throughout its fermentation.

Through its varying physicochemical properties, dietary fiber intake influences several metabolic processes, including the absorption of nutrients, carbohydrate and fat metabolism, and sterol metabolism. It has influence on colonic fermentation and affects the production of stools. In the large intestine, dietary fiber influences the colonic structure and barrier function, and as the large intestine encompasses a significant body of the human immune system, it is also likely to have influence on elements of immune function.

*Bacterial degradation of dietary fiber.*The large intestine plays a role in managing and conserving water and electrolytes, furthers the digestion of residual material passing from the small intestine, and provides a route for residual, nondigestible material and toxins to pass. The large intestine is the most heavily colonized region of the digestive tract, with up to 10^{11} to 10^{12} anaerobic bacteria for every gram of intestinal content [31]. These bacteria produce enzymes that further the digestion of dietary fiber passing undigested from the small intestine [32].

The extent of fiber degradation in the colon is dependent on the nature of the colonic bacterial flora, the transit time through the colon, and the physical and chemical composition of the fiber. Over 100 bacteria species (96-99% anaerobes) have been identified. Stephen and Cummings [33] have reported that bacteria may account for 41-57% of the dry weight of feces. The flora is largely saccharolytic and the bacteria that ferment cellulose and hemicellulose display a general specificity. This infers that the microbial spectrum of the lower intestine might be influenced by the fiber composition of the diet. Ingestion of a fiber-rich diet by normal subjects was associated with a decrease in secondary bile acids in the stool [34]. This may have been due in part to accelerated intestinal transit. Recently it has been demonstrated that the efficiency of bacterial polysaccharide metabolism in the colon is itself pH-dependent [35].

Digestion of polysaccharides varies between 30 to over 90%. Pectin and hemicellulose are almost completely lost during passage through the stool; cellulose is somewhat less well digested. Lignin, by virtue of its polymeric cross-linked structure, is resistant to bacterial degradation and is almost completely recovered in the stool. The physical structure of plant fiber also determines access to bacterial enzymes. Polysaccharides from older, highly lignified plant tissues are less well digested since physical encrustation and chemical bonding to lignin occur. In general, the fiber constituents of fruit and vegetables are much more fermentable than are cereal brans since the latter display thicker cell walls (lower surface to volume ratio) and a high degree of lignification (Table 2) [23].

Bacterial degradation of dietary fiber in the colon occurs in two stages. Extracellular hydrolysis of polysaccharides into component mono- and disaccharides is followed by intracellular anaerobic glycolysis [36]. The products of fermentation of dietary fiber include the short chain fatty acids, acetate, propionate, and butyrate. Other products are lactic and formic acids, ethanol, and CO_2. Excess H^+ released in the regeneration of NAD^+ is partially disposed of by the formation of H_2. Methane production from H_2 by colonic organisms has also been documented but is less common [32]. Increases in microbial mass from fiber fermentation contribute directly to stool bulk, which is a large part of the stool weight. Bacteria are about 80% water and have the ability to resist dehydration, and thus contribute to water-holding in fecal material.

Hidratability of dietary fiber. The water-holding capacity of dietary fiber has important physiological effects in both the upper and lower intestine. Hydration of fiber occurs by adsorption to the surface of the macromolecules and by entrapment within the interstices of the fibrous or gel matrix. The fiber saturation capacity or upper limit of water held is determined by the chemistry and morphology of the macromolecules and by the pH and electrolyte concentration of the surrounding medium. The presence of sugar residues with free polar groups confers a significant hydrophilic capacity to polysaccharides whereas intermolecular bonding, such as the ether crosslinkages between chains of cellulose molecules, has the opposite effect [30].

Particle size may also influence the water-holding capacity of fiber, since it determines the volume of the interstitial space within the fiber matrix available for water entrapment. Robertson and Eastwood [37] have demonstrated that the method of fiber preparation alters water-holding capacity profoundly although the chemical composition is unchanged. This suggests that the physical structure of fiber is the most important determinant of hydratability.

In the upper intestine, the water-holding capacity of fiber may affect the pattern of nutrient absorption, postprandial satiety, and intestinal motility.

Bounding of organic materials. A number of organic materials such as bile acids, other steroids, various toxic compounds, and bacteria may be reversibly bound to fiber as it passes along the gastrointestinal tract. Adsorption of bile acids has been best documented and is dependent on the composition of the fiber, the chemistry of the sterol, pH and osmolality of the surrounding medium [38,39].

Lignin is the most potent bile acid adsorbent and binding is apparently influenced by molecular weight, pH, and the presence of methoxyl and α-carbonyl groups on the lignin molecule [40]. Less information is available on the adsorption of the other materials by fiber. Fiber may interact with a number of organic substances within the enterohepatic circulation but there is not yet complete information on the physiological significance of such processes.

Cation exchange properties. The functional capacity of dietary fiber for cation exchange is well established. The effect is related to the number of free carboxyl groups on the sugar residues [41,42]. Calcium binding can be predicted on the basis of uronic acid content of fiber residues [43]. Formation of cation complexes with acidic polysaccharides is reflected in their effects on mineral balance, electrolyte absorption, and heavy metal toxicity.

Dietary fiber protective role in cancer. Cancer continues to be one of the number one health concerns of populations worldwide.

Historical observational and epidemiological studies from around the world have long supported that increased consumption of fruits and vegetables and high fiber intake provide a protective relationship between dietary fiber intake and colon cancer incidence [44-49]. But other reports [50,51], and 2 intervention trials [52,53], show no protective effect of fiber on recurrence of adenomatous polyps or, worse, possibly a negative effect as a result of certain fiber supplements. Early results from a European investigation, the European Prospective Investigation of Cancer (EPIC), involving more than half a million people in 10 European countries, indicates that dietary fiber provides strong protective effects against colon and rectal cancers [54,55]. The EPIC study data has been reported at various medical conferences, and is expected to produce more detailed information regarding the effects of diet on long-term health than previous studies have.

Poorly fermented fiber, such as that in cereal brans, has direct effects in the colon by promoting laxation, decreasing transit time, and binding substances such as bile acids and carcinogens. However, evidence to date is insufficient to determine if decreased colon cancer risk is a beneficial effect of this type of fiber.

Of particular interest is the utilization of fermentable fiber by the colonic microbiota that can result in changes to the numbers and types of bacteria and, more importantly, changes to their metabolic activities in terms of the formation of genotoxins, carcinogens, and tumor promoters.

Possible mechanisms for the anticarcinogenic and antitumorigenic effect of highly fermentable fibers are not completely understood and require further research. However, it is likely that some or all are involved in a metabolic chain reaction for the inhibitory effect to occur. The primary mechanisms involved with these effects are proposed to be: a reduction in the production of carcinogenic substances by decreasing the amount of pathogenic bacteria in the colon [56]; and/or lowering the colonic pH to affect pH-dependent enzymatic reactions, for example, secondary bile acid formation [57-59]; and/or reducing the amount of carcinogenic substances available to colonic mucosa by adsorption of the substances to the cell wall of the microbiota, by speeding up the intestinal transit time and by increasing colonic contents and thus diluting all components; and/or exerting inhibiting effects on initiation and promotion stages in colon cancer formation in which SCFA, particularly butyric acid, may play a key role [60-70].

Human metabolic and animal model studies indicate that beneficial effects of dietary fiber in relation to colon cancer development depend on the composition and physical properties of the fiber [71,72].

*Dietary fiber effect on glucose metabolism.*Under certain conditions, dietary fiber has a modulating effect on the glucose absorption rate and attendant hormonal responses. Mucilaginous fibers, such as guar, have the most potent effects on glucose metabolism. While a direct linkage between insufficient dietary fiber intake and diabetes has not been established, evidence that indicates decreased risk of the disease with increased dietary fiber consumption continues to grow [73,74]. Well fermented viscous fibers, either as part of a food or as a supplement that is well mixed with food, appear to offer the greatest potential benefit to reduce glycemic response and to increase insulin sensitivity [75-78].

The beneficial physiological effects of viscous fiber sources on blood glucose concentrations have been consistently demonstrated over the last 2 decades.

Dietary fiber protective role in coronary disease. Total serum cholesterol and low-density-lipoprotein (LDL) cholesterol levels are generally accepted as biomarkers, indicative of potential risk for developing coronary disease.

It is believed that the large amount of fiber from fruit, vegetable, and legumes in Mediterranean-type and vegetarian diets might be partly responsible for the low levels of plasma cholesterol observed [79-82]. A negative relationship between cereal fiber intake and death from coronary disease was reported [83].

Purified preparations of dietary fiber including cellulose, hemicellulose, lignin and pectin have been tested in man. None of these represent a single homogeneous entity and results of experiments have varied depending on the physical and chemical characteristics of the fiber isolate used [84-89].

Certain fiber-rich foodstuffs have been reported to significantly lower plasma total cholesterol concentration [90]. Some experiments showed reduced plasma cholesterol levels when calories as sucrose, lactose, and milk protein were replaced by sugars, starch, protein, and dietary fiber in the form of fresh fruits, vegetables, and legumes [91].

2. Conclusion

Dietary fiber is a ubiquitous component of plant foods and includes materials of diverse chemical and morphological structure, resistant to the action of human alimentary enzymes but that may be digested by microflora in the gut.

Dietary fiber has been recognized to have considerable health benefits. Extensive research has been carried out into the physiological effects of dietary fiber and there is evidence that a low intake may be associated with a number of diseases.

Dietary fiber is a polymer matrix with variable physicochemical properties including susceptibility to bacterial fermentation, water-holding capacity, cation-exchange, and adsorptive functions. These properties determine physiological actions of fiber.

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References

1. Kritchevsky, D., Dietary Fiber, *Annual Review of Nutrition* **1988**, *8*, 301-328.
2. Dreher, M.L., *Handbook of Dietary Fiber: An Applied Approach*, Marcel Dekker, Inc., New York, 1987.
3. DeVries, J.W.; Rader, J.I. Historical perspective as a guide for identifying and developing applicable methods for dietary fiber, *Journal of AOAC International* **2005**, *88*(5), 1349-1366.
4. Kellogg, J.H., The New Dietetic; *A Guide to The Scientific Feeding in Health and Disease*, Modern Medicine Publishing, Battle Greek, Michigan, 1923.
5. Khan Khattak, M.M.A., Physiological Effects of Dietary Complex Carbohydrates and its Metabolites Role in Certain Diseases, *Pakistan Journal of Nutrition* **2002**, *1*(4), 161-168.
6. Hipsley, E. H., Dietary “Fibre” and Pregnancy Toxaemia, *British Medical Journal* **1953**, *2*, 420-422.
7. DeVries, J.W.; Prosky, L.; Li, B.; Cho, S., A Historical Perspective on Defining Dietary Fiber, *Cereal Foods World* **1999**, *44*(5), 367-369.
8. Trowell, H.C., Crude Fibre, Dietary Fibre, and Atherosclerosis, *Atherosclerosis*, **1972**, *16*, 138-140.
9. Trowell, H.C., Ischemic Heart Disease and Dietary Fibre, *American Journal of Clinical Nutrition* **1972**, *25*, 926-932.
10. Burkitt, D.P.; Walker, A. R. P.; Painter, N. S., Effect of Dietary Fibre on Stools and Transit Times and Its Role in The Causation of Disease, *Lancet* **1972**, *2*, 1407-1411.
11. Trowell, H.C., Definition of Dietary Fibre, *Lancet* **1974**, *1*, 503-505.
12. Painter, N.S., *Diverticular Disease of the Colon: A Deficiency Disease of Western Civilization*, William Heinemann Medical Books Ltd., London, 1975, 68-73.
13. Trowell, H.C.; Southgate, D.A.T.; Wolever, T.M.S.; Leeds, A.R.; Gassull, M.A.; Jenkins, D.J.A., Dietary Fiber Redefined, *Lancet* **1976**, *1*, 967.

14. Lee, S.C.; Prosky, L., International Survey on Dietary Fiber Definition, Analysis, and Reference Materials, *Journal of AOAC International* **1995**, *78*, 22-36.
15. Cho, S. S.; Prosky, L., *Summary of AOAC Survey on Complex Carbohydrates/Dietary Fiber*. In: *Complex Carbohydrates/Dietary Fiber,* S. S. Cho, L. Prosky, and M. Dreher, Eds., Marcel Dekker, New York, NY, 1999, 131-143.
16. Caldwell, E. F.; Nelsen, T. C., Development of an Analytical Reference Standard for Total, Insoluble, and Soluble Dietary Fiber, *Cereal Foods World* **1999**, *44*(5): 360-362.
17. Cummings, J.H.; Englyst, H.N., Fermentation in the Human Large Intestine and the Available Substrate, *American Journal of Clinical Nutrition* **1987**, *45*, 1243-1255.
18. Kay, R.M., Dietary Fibre, *Journal of Lipid Research* **1982**, *23*, 221-242.
19. British Nutrition Foundation, *Complex Carbohydrates in Foods: Report of the British Nutrition Foundation's Task Force*, Chapman and Hall, Ltd., London, 1990.
20. Prosky, L, When Is Dietary Fiber Considered A Functional Food?, *BioFactors* **2000**, *12*(1-4), 289-297.
21. Cho, S.S.; DeVries, J.W.; Prosky, L., *The Structure and Chemistry of Dietary Fiber.* In: *Dietary Fiber Analysis and Applications*, AOAC International, Gaithersburg, MD, 1997, 11-48.
22. Kolattukudy, P.E, Structure, Biosynthesis and Biodegradation of Cutin and Suberin, *Annual Review of Plant Physiology* **1981**, *32*, 539-567.
23. Tungland, B.C.; Meyer, D., Nondigestible Oligo- and Polysaccharides (Dietary Fiber): Their Physiology and Role in Human Health and Food, *Comprehensive Reviews in Food Science and Food Safety* **2002**, *1*, 73-92.
24. Theander, O.; Aman, P., *The Chemistry, Morphology and Analysis of Dietary Fiber Components*. In: *Dietary Fibers: Chemistry and Nutrition*. G.E. Inglett and S.I. Fakehag (eds.), Academic Press, New York, **1979**, 215-244.
25. Kertesz, Z.I., *Polyuronides*. In: *Comprehensive Biochemistry*, M. Florkin and E. H. Stotz (eds.), Elsevier, New York, **1963**, *5*, 233-245.
26. Southgate, D. A. T.; Branch, W.J.; Hill, M.J.; Draser, B.S.; Davies, P.S.; McLean-Baird, I., Metabolic Responses to Dietary Supplements of Bran, *Metabolism* **1976**, *25*, 1129-1135.
27. Schneeman, B.O., Dietary Fiber and Gastrointestinal Function, *Nutrition Research* **1998**, *18*(4), 625-632.
28. Jones, J., Update on Defining Dietary Fiber, *Cereal Foods World* **2000**, *45*(5), 219-220.
29. Kritchevsky, D., *Dietary Fiber in Health and Disease*. In: *Proceedings of the 1st International Conference on Dietary Fiber; Dublin, Ireland; May 2000*, McCleary BV, Prosky L (eds.), Blackwell Science, Oxford, U.K., 2000, 38.
30. Aspinall, G.O., *Carbohydrate Polymers of Plant Cell Walls*. In*: Biogenesis of Plant Cell Wall Polysaccharides*, F. Loewas (ed.), Academic Press, New York, 1973, 95-115.
31. Gibson, G.R.; Roberfroid, M.R., Dietary Modulation of the Human Colonic Microbiota: Introducing the Concept of Prebiotics, *Journal of Nutrition* **1995**, *125*(6), 1401-1412.
32. Nordgaard, I.; Mortensen, P.B., Digestive Processes in the Human Colon, *Nutrition* **1995**, *11*(1), 37-45.
33. Stephen, A.M.; Cummings, J.H., 1980. Mechanism of Action of Dietary Fiber in the Human Colon, *Nature* **1980**, *284*, 283-284.
34. Ullrich, I.H.; Lai, H.L.; Vona, L.; Riea, R.L.; Albrink, M.J., Dietary Fiber Alters Fecal Steroid Composition, *American Journal of Clinical Nutrition* **1980**, *33*, 261-264.
35. Perman, J.A.; Modler, S.; Olson, A.C., Role of pH in Production of Hydrogen from Carbohydrates by Colonic Bacterial Flora, *Journal of Clinical Investigation* **1980**, *67*, 643-650.
36. Pool-Zobel, B.L.; Bertram, B.; Knoll, M.; Lambertz, R.; Neudecker, C.; Schillinger, U.; Schmezer, P.; Holzapfel, W.H., Antigenotoxic Properties of Lactic Acid Bacteria *in Vivo* in The Gastrointestinal Tract of Rats, *Nutrition and Cancer* **1993**, *20*, 271-281
37. Robertson, J.A.; Eastwood, M.A., An Examination of Factors Which May Affect the Water-Holding Capacity of Dietary Fibre, *British Journal of. Nutrition* **1981**, *45*, 83-88.
38. Story, J.A.; Kritchevsky, D., Comparison of the Binding of Various Bile Acids and Bile Salts *in vitro* by Several Types of Fiber, *The Journal of Nutrition* **1976**, *106*, 1292-1294.
39. Eastwood, M.A.; Mowbray, L., The Binding of the Cmponents of Mixed Micelle to Dietary Fiber, *American Journal of Clinical Nutrition* **1976**, *29*, 1461-1467.
40. Kay, R.M.; Strasberg, S.M.; Petrunka, C.N.; Wayman, M., *Differential Adsorption of Bile Acids by Lignins*. In: *Dietary Fibers: Chemistry and Nutrition*, Academic Press, New York, 1979, 57-66.
41. Grant, G.T.; Morris, E.R.; Rees, D.A.; Smith, P.J.C.; Thom, D., Biological Interactions between Polysaccharides and Divalent Cations: the Egg-Box Model, *FEBS Letters* **1973**, *32*, 195-198.
42. McConnell, A.A.; Eastwood, M.A.; Mitchell., W.D., Physical Characteristics of Vegetable Foodstuffs That Could Influence Bowel Function, *Journal of the Scence of Food and Agriculture* **1974**, *25*, 1457-1464.

43. James, W.P.T.; Branch, W.J.; Southgate, D.A.T., Calcium Binding by Dietary Fibre, *The Lancet.* **1978**, *1*, 638-639.
44. Trock, B.; Lanza E.; Greenwald, P., Dietary Fiber, Vegetables, and Colon Cancer: Critical Review and Meta-Analyses of the Epidemiologic Evidence, *Journal of the National Cancer Institute* **1990**, *82*, 650-661.
45. Steinmetz, K.A.; Porter, J.D., Vegetables, Fruits, and Cancer, I. Epidemiology, *Cancer Causes & Control* **1991**, *2*, 325-357.
46. Howe, G.R.; Benito, E.; Castello, R., Dietary Intake of Fiber and Decreased Risk of Cancers of the Colon and Rectum: Evidence from the Combined Analysis of 13 Case-Control Studies, *Journal of the National Cancer Institute* **1992**, *84*, 1887-1896.
47. Byers, T., *Dietary Fiber and Colon cancer Risk: the Epidemiologic Evidence*. In: *Dietary Fiber*, Plenum Press, New York, 1995, pp. 183-190
48. Byers, T., Food Frequency Dietary Assessment: How Bad Is Good Enough?, *The American Journal of Epidemiology* **2001**, *154*, 1087-1088
49. Byers, T., Diet, Colorectal Adenomas, and Colorectal Cancer, *The New England Journal of Medicine* **2000**, *342* (16), 1206-1207
50. Fuchs, C.S.; Giovannucci, E.L.; Colditz, G.A.; Hunter, D.J.; Stampfer, M.J.; Rosner, B.; Speizer, F.E.; Willett, W.C., Dietary Fiber and the Risk of Colorectal Cancer and Adenoma in Women, *The New England Journal of Medicine* **1999**, *340*(3), 169-176
51. Bonithon-Kopp, C.; Kronborg, O.; Giacosa, A.; Räth, U.; Faivre, J., Calcium and Fibre Supplementation in Prevention of Colorectal Adenoma Recurrence: a Randomised Intervention Trial, *The Lancet* **2000**, *356*, 1300-1306
52. Alberts, D.S.; Martínez, M.E.; Roe, D.J.; Guillén-Rodríguez, J.M.; Marshall, J.R.; van Leeuwen, J.B.; Reid, M.E.; Ritenbaugh, C.; Vargas, P.A.; Bhattacharyya, A.B.; Earnest, D.L.; Sampliner, R.E., Lack of Effect of a High-Fiber Cereal Supplement on the Recurrence of Colorectal Adenomas, *The New England Journal of Medicine* **2000**, *342*(16), 1156-1162.
53. Schatzkin, A.; Lanza, E.; Corle, D.; Lance, P.; Iber, F.; Caan, B.; Shike, M.; Weissfeld, J.; Burt, R.; Cooper, M.R.; Kikendall, J.W.; Cahill, J., Lack of Effect of a Low-Fat, High-Fiber Diet on the Recurrence of Colorectal Adenomas, *The New England Journal of Medicine* **2000**, *342*(16), 1149-1155.
54. Bingham, S.A., Dietary Assessments in The European Prospective Study of Diet and Cancer, *European Journal of Cancer Prevention* **2001**, *6*, 118-124.
55. Bingham, S.A.; Day, N.E.; Luben, R.; Ferrari, P.; Slimani, N.; Norat, T.; Clavel-Chapelon, F.; Kesse, E.; Nieters, A.; Boeing, H.; Tjønneland, A.; Overvad, K.; Martinez, C.; Dorronsoro, M.; Gonzalez, C.A.; Key, T.J.; Trichopoulou, A.; Naska, A.; Vineis, P.; Tumino, R.; Krogh, V.; Bueno-de-Mesquita, H.B.; Peeters. P.H.; Berglund, G.; Hallmans, G.; Lund, E.; Skeie, G.; Kaaks, R.; Riboli. E., Dietary Fibre in Food and Protection Against Colorectal Cancer in the European Prospective Investigation into Cancer and Nutrition (EPIC): An Observational Study, *The Lancet* **2003**, *361*, 1496-1501.
56. Rumney, C.; Rowland, I., Non-digestible Oligosaccharides Potential Anticancer Agents? *BNF Nutrition Bulletin* **1995**, *20*, 194-203.
57. Buddington, R.K.; Williams, C.H.; Chen, S.C.; Witherly, S.A., Dietary Supplement of Neosugars Alters the Fecal Flora and Decreases Activities of Some Reductive Enzymes in Human Subjects, *American Journal of Clinical Nutrition* **1996**, *63*, 709-716.
58. Rowland, I.R.; Rumney, C.J.; Coutts, J.T.; Lievense, L.C., Effect of Bifidobacterium Longum and Inulin on Gut Bacterial Metabolism and Carcinogen-Induced Aberrant Crypt Foci in Rats, *Carcinogenesis* **1998**, *19*, 281–285.
59. Rowland, I.R., *Toxicology of the Colon: Role of the Intestinal Flora*. In: *Human Colonic Bacteria: Role in Nutrition, Physiology and Pathology*, CRC Press, Boca Raton, Fla, 1995, 155-174.
60. Hague, A.; Manning, A.M.; Hanlon, K.A.; Huschtscha, L.I.; Hart, D.; Paraskeva, C., Sodium Butyrate Induces Apoptosis in Human Colonic Tumour Cell Lines in A P53-Independent Pathway: Implications for the Possible Role of Dietary Fibre in the Prevention of Large-Bowel Cancer, *International Journal of Cancer* **1993**, *55*, 498-505.
61. Pool-Zobel, B.L.; Bertram, B.; Knoll, M.; Lambertz, R.; Neudecker, C.; Schillinger, U.; Schmezer, P.; Holzapfel, W.H., Antigenotoxic Properties of Lactic Acid Bacteria *in vivo* in the Gastrointestinal Tract of Rats, *Nutrition and Cancer* **1993**, *20*, 271–82.
62. Pool-Zobel, B.L.; Neudecker, C,; Domizlaff, I.; Schillnger, U.; Rumney, C.; Moretti, M.; Vilarini, I.; Scasseellati-Sforzolini, R.; Rowland, I., *Lactobacillus*- and *Bifidobacterium*-Mediated Antigenotoxicity in the Colon of Rats, *Nutrition and Cancer* **1996**, *26*, 365–380.
63. Reddy, B.S.; Rivenson, A., Inhibitory Effect of *Bifidobacterium Longum* on Colon, Mammary and Liver Carcinogenesis Induced by 2-Amino-3-Methylimidazo(4,5-*F*)Quinoline, A Food Mutagen, *Cancer Research* **1993**, *53*, 3914–3918.
64. Scheppach, W.; Bartram, H.P.; Richter, F., Role of Short-Chain Fatty Acids in the Prevention of Colorectal Cancer, *European Journal of Cancer* **1995**, *31A,* 1077-1080.

65. Pierre, F.; Perrin, P.; Champ, M.; Bornet, F.; Meflah, K.; Menanteau, J., Short Chain Fructo-Oligosaccharides Reduce the Occurence of Colon Tumors and Develop Gut-Associated Lymphoid Tissue in Min Mice, *Cancer Research* **1997**, *57*, 225-228.
66. Pierre, F.; Perrin, P.; Bassonga, E.; Bornet, F.; Meflah, K.; Menanteau, J., T., Cell Status Influences Colon Tumors Occurence in Min Mice Fed Short Chain Fructo-Oligosaccharides as a Diet Supplement, *Carcinogenesis* **1999**, *20*, 1953-1956.
67. Reddy, B.S., Prevention of Colon Cancer by Pre- and Probiotics: Evidence from Laboratory Studies, *British Journal of Nutrition* **1998**, *80*, 219-223.
68. Reddy, B.S.; Hamid, R.; Rao, C., Effect of Dietary Oligofructose and Inulin on Colonic Preneoplastic Aberrant Crypt Formation, *Carcinogenesis* **1997**, *18*, 1371-1374.
69. Verghese, M.; Chawan, C.B.; Williams, L.; Rao, D.R., Dietary Inulin Supresses Azoxymethane-Iduced Preneoplastic Abberant Crypt Foci in Rat Colon. In: *Proceedings of the Nutritional and Health Benefits of Inulin and Oligofructose Conference; Bethheda, Md. Pennsylvania State Univ.*, 1998, P55.
70. Peridgon, G.; Waldez, J.C.; Rachid, M., Antitumor Activity of Yoghurt: Study of Possible Imune Mechanism, *Journal of Dairy Research* **1998**, *65*, 129-138
71. Reddy, B.S.; Engle, A.; Simi, B.; Goldman, M., Effect of Dietary Fiber on Colonic Bacterial Enzymes and Bile Acids in Relation to Colon Cancer, *Gastroenterology* **1992**, *102*, 1475-1482.
72. Reddy, B.S., Dietary Fiber and Colon Cancer: Animal Model Studies, *Preventive Medicine* **1995**, *6*, 559-565.
73. Jenkins, D.J.; Kendall, C.W.C.; Axelsen, M.; Augustin, L.S.A.; Vuksan, V., Viscous and Nonviscous Fibres, Nonabsorbable and Low Glycaemic Index Carbohydrates, Bloodlipids and Coronary Heart Disease, *Current Opinion in Lipidology* **2000**, *11*, 49–56.
74. Chandalia, M.; Garg, A.; Lutjohann, D. ; von Bergmann, K.; Grundy, S.M.; Brinkley, L.J., Beneficial Effects of High Dietary Fiber Intake in Patients with Type 2 Diabetes Mellitus, *The New England Journal of Medicine* **2000**, *342(*19), 1392-8.
75. Anderson, J.W.; Smith, B.M.; Gustafson, N.J., Health Benefits and Practical Aspects of High-Fiber Diets, *American Journal of Clinical Nutrition* **1994**, *59* (suppl), 1242-1247.
76. Anderson, J.W., *High-Fiber Diets for Obese Diabetic Men on Insulin Therapy: Short-Term and Long-Term Effects*. In: *Dietary Fiber and Obesity*, Alan R Liss, Inc., New York, 1985, 133-159.
77. Wolever, T.M.S.; Jenkins, D.J.A., *Effect of Dietary Fiber and Foods on Carbohydrate Metabolism*. In: *CRC Handbook of Dietary Fiber in Human Nutrition*, CRC Press, Boca Raton, 1993, 111–152.
78. Fukagawa, N.K.; Anderson, J.W.; Hageman, G.; Young, V.R.; Minaker, K.L., Highcarbohydrate, High-Fiber Diets Increase Peripheral Insulin Sensitivity in Healthy Young and Old Adults, *American Journal of Clinical Nutrition* **1990**, *52*, 524–528.
79. Anderson, J.F.; Grande, F.; Keys, A., Cholesterollowering Diets. Experimental Trials and Literature Reviews, *Journal of the American Dietetic Association* **1973**, *62*,133-142.
80. Phillips, R.L.; Leman, F.R.; Beeson, W.L.; Kuzman, J.W., Coronary Heart Disease Mortality among Seventh-Day Adventists with Differing Dietary Habits: A Preliminary Report, *American Journal of Clinical Nutrition* **1978**, *31*, S191-S198.
81. Hardinge, M.G.; Chambers, A.C.; Crooks, H.; Stare, F.J., Nutritional studies of vegetarians. III: Dietary levels of fibre, *American Journal of Clinical Nutrition* **1958**, *6*, 523-525.
82. Sacks, F. M.; Castelli, W.P.; Donner, A.; Kass. E.H., Plasma Lipids and Lipoproteins in Vegetarians and Controls, *The New England Journal of Medicine* **1978**, *292*, 1148-1151.
83. Morris, J. N.; Marr, J.W.; Clayton, D.G., Diet and Heart: A Post-Script, *British Medical Journal* **1977**, *2*, 1307-1314.
84. Jenkins, D.J.; Wolever, T.; Rao, A.V.; Hegele, R.A.; Mitchell, S.J.; Ransom, T.; Boctor, D.L.; Spadafora, P.J.; Jenkins, A.L.; Mehling, C.; Relle, L.K.,; Connelly, P.W.; Story, J.A.; Furumoto, E.J.; Corey, P.N.; Wursch, P., Effect on Blood Lipids of Very High Intakes of Fiber in Diets Low in Saturated Fat and Cholesterol, *New Englan Journal of Medicine* **1993**, *329*, 21-26.
85. Jenkins, D.J.; Kendall, C.W.; Vuksan, V.; Vidgen, E.; Parker, T.; Faulkner, D.; Mehling, C.C.; Garsetti, M.; Testolin, G.; Cunnane, S.C.; Ryan, M.A.; Corey, P.N.; (2002). Soluble Fiber Intake at A Dose Approved by The US Food and Drug Administration for A Claim of Health Benefits: Serum Lipid Risk Factors for Cardiovascular Disease Assessed in A Randomized Controlled Crossover Trial, *American Journal of Clinical Nutrition* **2002**, *75*, 834-839.
86. Anderson, J.W.; Garrity, T.F.; Wood, C.L.; Whitis, S.E.; Smith, B.M.; Oeltgen, P.R., Prospective, Randomized, Controlled Comparison of the Effects of Low-Fat and Low-Fat Plus High-Fiber Diets on Serum Lipid Concentrations, *American Journal of Clinical Nutrition* **1992**, *56*, 887-894.
87. Anderson, J.W.; Gilinsky, N.H.; Deakins, D.A.; Smith, S.F.; O'Neal, D.S.; Dillon, D.W.; Oeltgen, P.R., Lipid responses of hypercholesterolemic men to oat-bran and wheat-bran intake, *American Journal of Clinical Nutrition* **1991**, *54*, 678–683.

88. Anderson, J.W.; Allgood, L.D.; Turner, J.; Oeltgen, P.R.; Daggy, B.P., Effects of psyllium on glucose and serum lipid responses in men with type 2 diabetes and hypercholesterolemia, *American Journal of Clinical Nutrition* **1999**, *70*, 466–473.
89. Anderson, J.W.; Allgood, L.D.; Lawrence, A.; Altringer, L.A.; Jerdack, G.R.; Hengehold, D.A.; Morel, J.G., Cholesterol-Lowering Effects of Psyllium Intake Adjunctive to Diet Therapy in Men and Women with Hypercholesterolemia: Meta-Analysis of 8 Controlled Trials, *American Journal of Clinical Nutrition* **2000**, *71*, 472–479.
90. Miettinen, T.A., *Effects of Dietary Fiber on Serum Lipids and Cholesterol Metabolism in Man*. In: *Atherosclerosis*, Springer-Verlag, New York, 1980, 311-315.
91. Keys, A.; Anderson, J.T.; Grande,F.,1960. Diettype (fats constant) and blood lipids in man, *The Journal of Nutrition* **1960**, *70*, 257-266.