Closing the Dietary Fiber Gap

Aligning Dietary Fiber Policy, Research, and Communication

Calorie Control Council

HEALTHY EATING & EXERCISE FOR LIFE™

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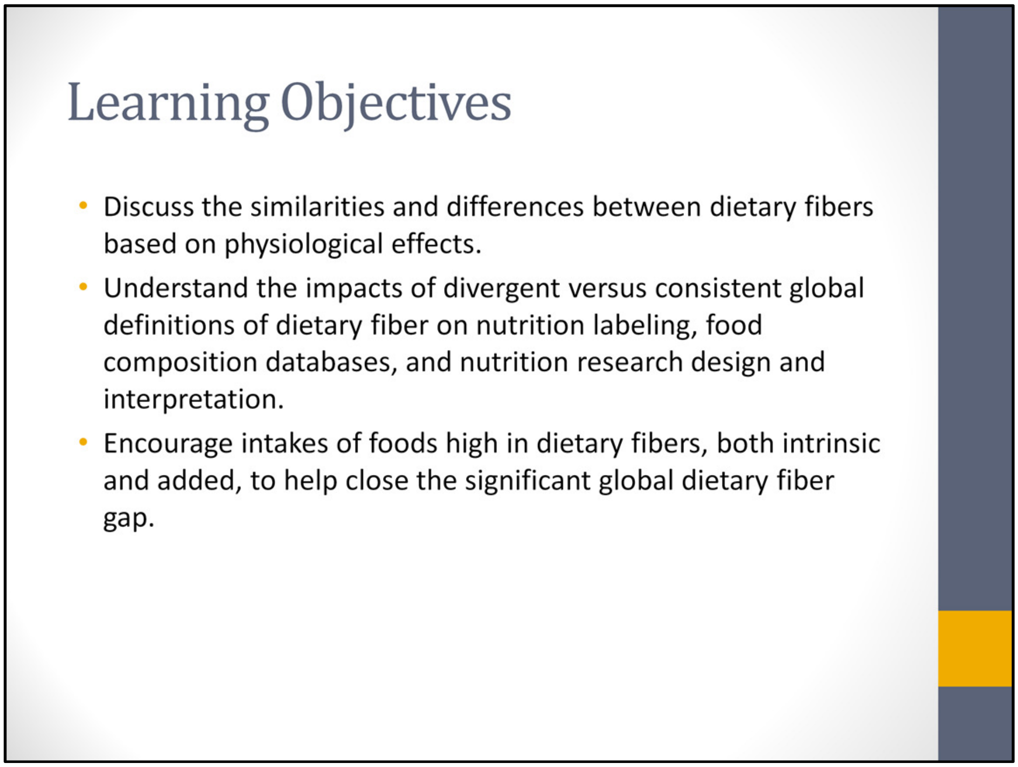
"Closing the Dietary Fiber Gap: Aligning Dietary Fiber Policy, Research, and Communication," is a one-hour self-study continuing professional education (CPE) module for registered dietitians (RDs) and dietetic technicians, registered (DTRs). The information in this module is at Level 2, meaning that prior knowledge of, but not expertise in, the topic is assumed.

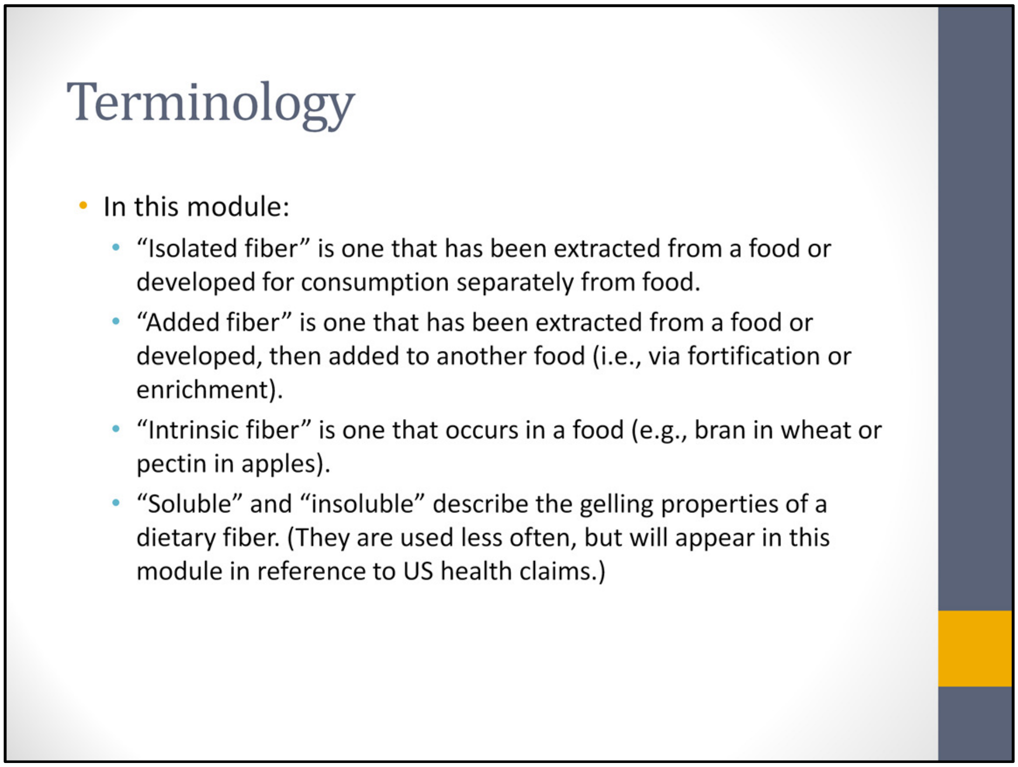
Suggested Learning Need Codes:

- 2070: Macronutrients: carbohydrate, fat, protein, fiber, water
- 3020: Assessment of target groups, populations
- 4030: Dietary guidelines, DRIs, Food Guide Pyramid, food labeling
- 4040: Disease prevention



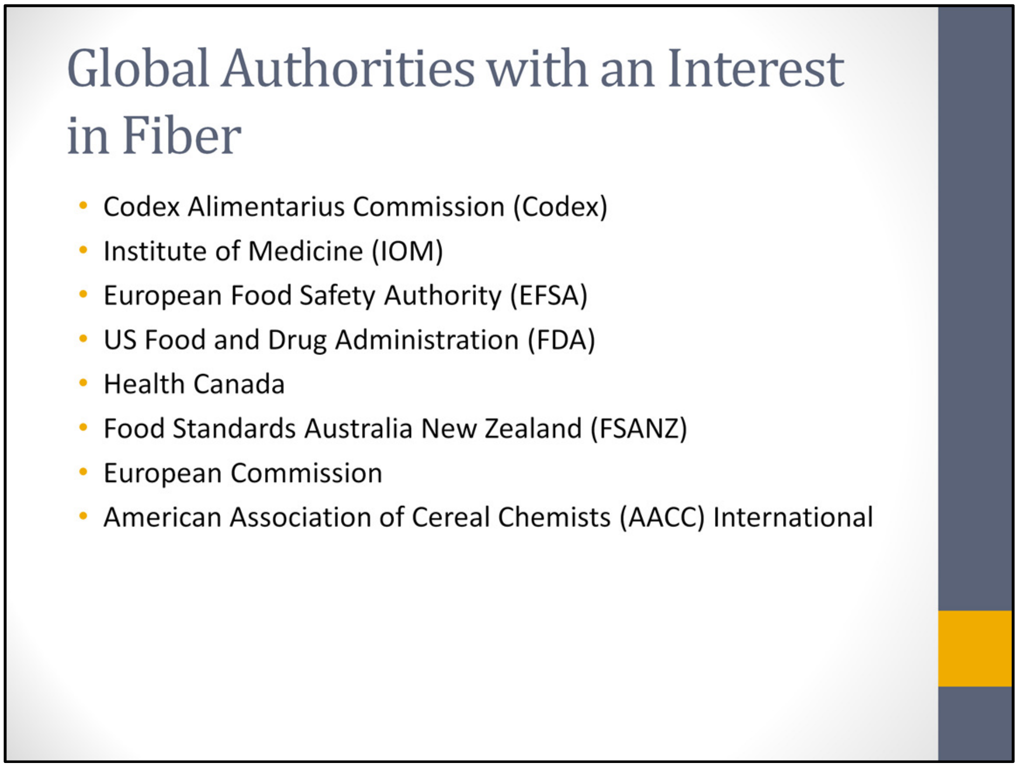
At the end of this module, the dietetic professional will be able to:

- Discuss the similarities and differences between dietary fibers based on physiological effects.
- Understand the impacts of divergent versus consistent global definitions of dietary fiber on nutrition labeling, food composition databases, and nutrition research design and interpretation.
- Encourage intakes of foods high dietary fibers, both intrinsic and added, to help close the significant global dietary fiber gap.



This module will address the many ways in which dietary fibers differ, and explore the differences that are based on physiological action versus other factors. Terms that are used to describe different types of fibers in the published research literature and global dietary recommendations are included here for clarity:

- "Isolated fiber" is one that has been extracted from a food or developed for consumption separately from food.
- "Added fiber" is one that has been extracted from a food or developed, then added to another food (i.e., via fortification or enrichment).
- "Intrinsic fiber" is one that occurs in a food (e.g., bran in wheat or pectin in apples).
- "Soluble" and "insoluble" describe the gelling properties of a dietary fiber, which is only one of its many physical properties. In 2005, the Institute of Medicine (IOM) recommended against using these terms because they do not capture the health benefits of dietary fiber (more on slides 10-16). However, these terms are common in the scientific literature and in US health claims, as the transition away from using them is in progress, therefore they will appear in this module.



As dietary fiber research has advanced, it has become apparent that dietary fibers are a group of compounds that have both similarities and differences in terms of physiological effect. Working out which differences matter for human health is the important work of government agencies, as well as standard-setting, health, and scientific organizations around the globe. Before diving into global dietary fiber definitions and regulations, it will be helpful to understand the roles these various organizations play globally and within various countries.

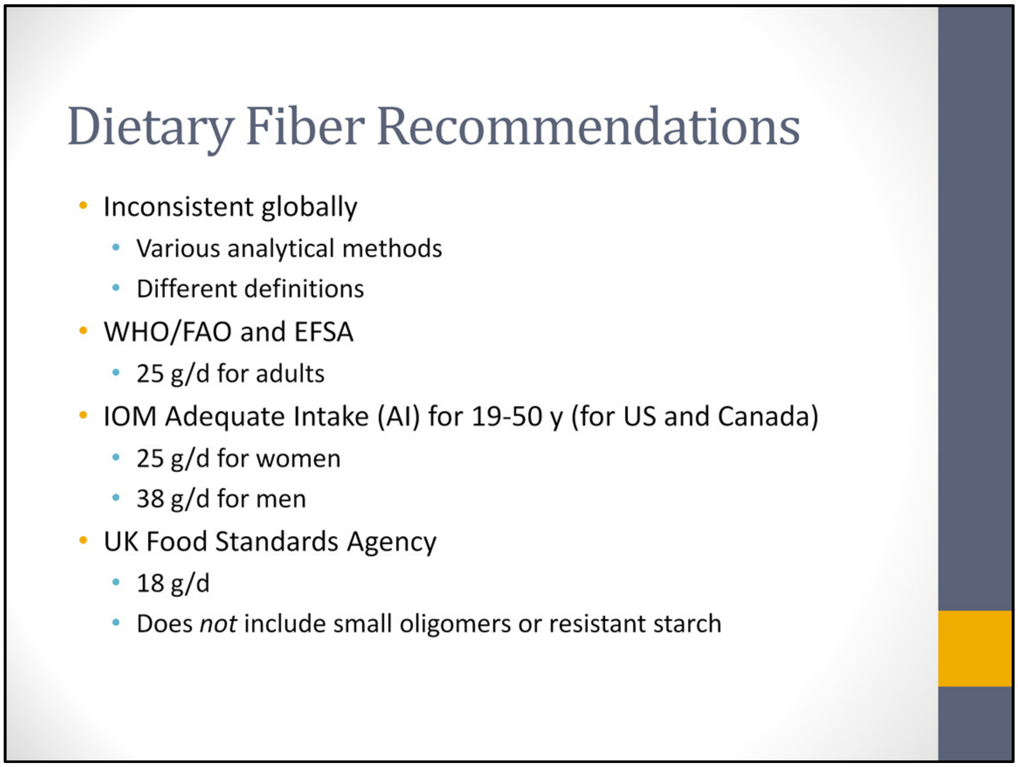
The **Codex Alimentarius Commission (Codex)**, was established by the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) in 1963. Participants include 180 countries representing 99% of the world's population. It was formed to set international food standards, guidelines, and codes of practice that are aimed at harmonizing the safety, quality, and fairness of international food trade.

The **Institute of Medicine (IOM)** and the **European Food Safety Authority (EFSA)** are scientific authorities that inform government regulation and public health policy in the United States of America and the European Union, respectively.

Regulatory agencies mentioned in this module include the **US Food and Drug Administration (FDA)**, **Health Canada**, **Food Standards Australia New Zealand (FSANZ)**, and **European Commission (legislative body of the European Union)**.

The **American Association of Cereal Chemists (AACC) International**, as the name implies, are experts in cereal chemistry, providing technical expertise to inform definitions and procedures for cereal grain composition analysis.

GLOBAL DIETARY FIBER RECOMMENDATIONS

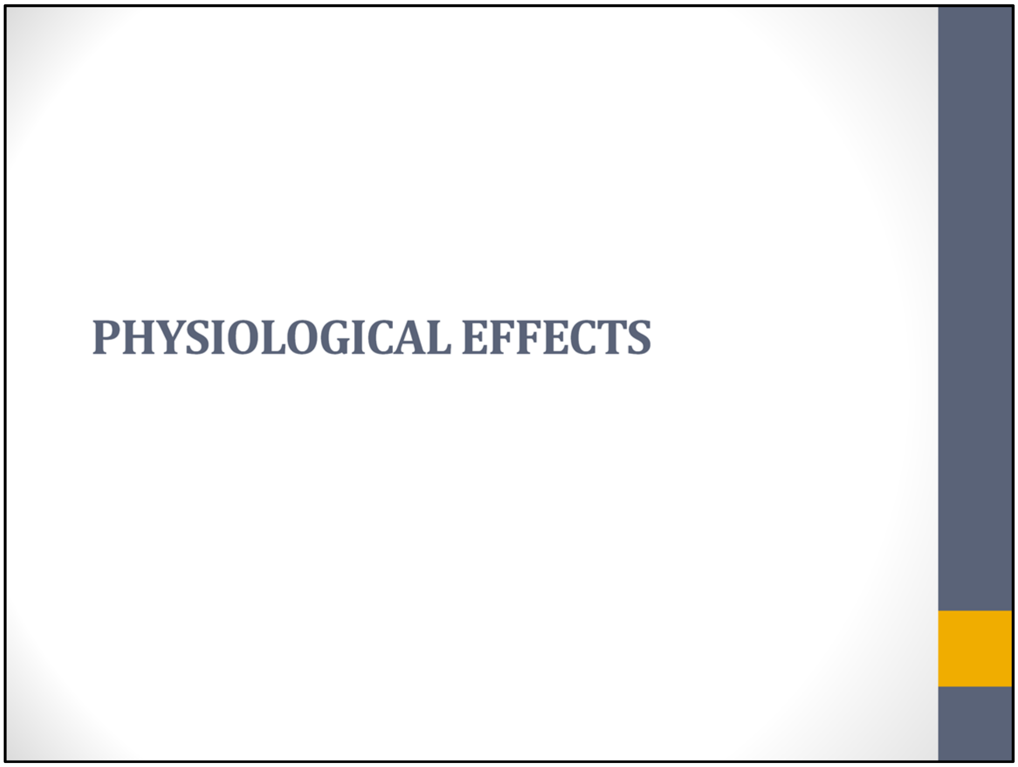


Examination of global dietary fiber recommendations reveals challenges with the use of various methods for analyzing the dietary fiber content of foods and different definitions of dietary fiber and its health effects. Recommendations for dietary fiber intake vary globally from 20-40 g/d.

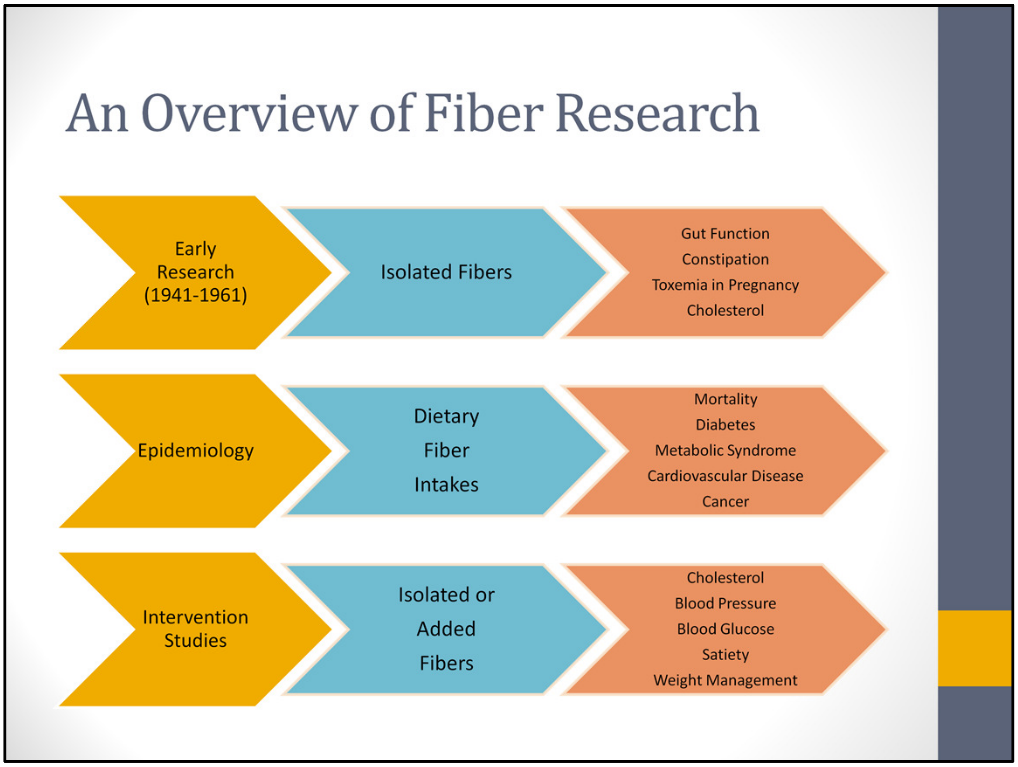
The World Health Organization (WHO)/ Food and Agriculture Organization of the United Nations (FAO) and European Food Safety Authority (EFSA) both recommend 25 g/d for adults, with EFSA basing its recommendation on the amount needed for healthy laxation. (Nishida 2004; EFSA 2010) Adequate Intake (AI) levels of dietary fiber observed to reduce risk of coronary heart disease (CHD) form the basis for Institute of Medicine (IOM) recommendations in the US and Canada. Thus the recommendation for adults (19-50 years of age) is 25 g/d for women and 38 g/d for men. (IOM 2002)

The UK Food Standards Agency (FSA) recommends 18 g/d, a much lower level, which refers only to non-starch polysaccharides, not small oligomers or resistant starch. (UK FSA 2006) The recommendation is based on the analytical method used in the UK to quantify non-starch polysaccharides, which includes both insoluble fiber (cellulose, insoluble non-cellulosic polysaccharides) and soluble fiber (soluble cellulosic polysaccharides), but does not include small oligomers or resistant starch. (FSA 2002) In contrast, Codex uses a method which has been adjusted to also quantify oligomers and resistant starch. (McCleary 2007)

What is the basis for most dietary fiber recommendations? Conditions such as chronic constipation are reported in both adults and children. (Mugie et al 2011; Tabbers et al 2011) But concerns about inadequate dietary fiber intake go beyond constipation in that low intakes may predispose children to and increase risk among adults for many chronic conditions, including CHD, and possibly diabetes and obesity. (Kranz et al 2012; Lanigan et al 2007) Fibers' role in gut health is also increasingly understood to affect immune response. Dietary fiber recommendations, however, are based on laxation and CHD risk because of the strength of the science for these health effects. As will be discussed further in this module, how fibers are defined has had an impact on research.



One distinction that has been emphasized in fiber definitions is whether it is intrinsic to a food or added. Research has demonstrated that both intrinsic and added fibers are of interest because of their overlapping and synergistic physiological and health effects.



Much early research on dietary fibers was conducted with isolated fibers, introducing their effects on laxation and cholesterol. (Duckworth and Godden 1941; Hipsley 1953; Schmidt and Kleibel 1952; Vignec and Mitty 1952; Keys et al 1961)

Several epidemiological studies have found inverse associations between intakes of dietary fiber, whole grains, and/or fibers from specific foods and mortality, diabetes, metabolic syndrome, cardiovascular disease, and associated markers of disease. (Threapleton, Greenwood, Evans et al 2013a; Ye et al 2012; Threapleton, Greenwood, Burley, et al 2013; Chen et al 2013; Threapleton, Greenwood, Evans et al 2013b; Coleman et al 2013; Zhang, Xu, Ma, et al 2013; Zhang, Xu, Liu, et al 2013; Aune et al 2012; Park et al 2011; Aune et al 2011; McKeown et al 2009; Anderson et al 2004; McKeown et al 2004)

Intervention studies with isolated or added fibers have demonstrated improved biomarkers of chronic diseases, such as cholesterol, blood pressure, and blood glucose . (Papathanasopoulos et al 2010; El Khoury et al 2012; Bajorek et al 2010; Wolfram et al 2011; Brennan 2005; Chearskul et al 2007) Dietary fibers may also increase satiety and help with weight management. (Papathanasopoulos et al 2010; Anderson et al 2004; Anderson et al 2009; Babio et al 2010; Macfarlane et al 2001; De Preter et al 2011; Galisteo et al 2008; Rock 2007; Watzl et al 2005; Sánchez et al 2012; Willis et al 2009; Weickert et al 2012) More studies are needed to show how changes in gut microbiota, whether related to fibers or other factors, modulate disease risk markers and promote good health. (De Preter et al 2011; Weickert et al 2012; Conterno et al 2011)

Physiological Properties of Fibers

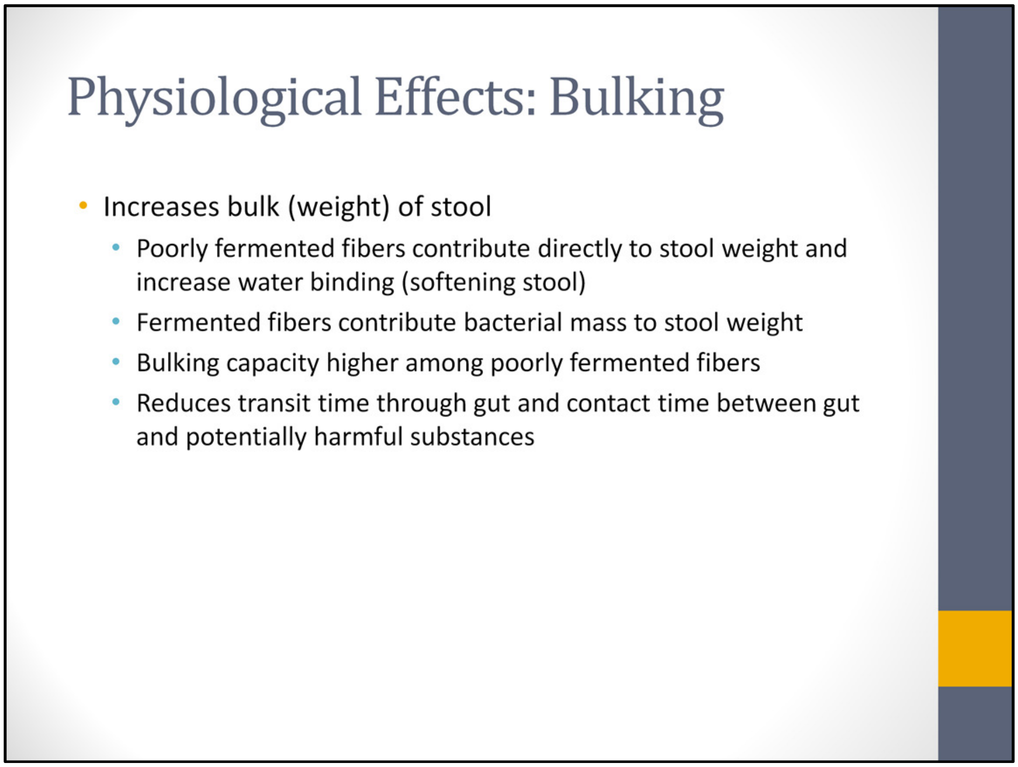
- Bulking
- Viscocity
- Fermentation

The physiological effects of dietary fibers are rooted in their bulking, viscocity, and fermentation properties.

Physiological Properties of Some Isolated Fibers

DIETARY FIBER	BULKING	VISCOUS	FERMENTABLE
Arabinoxylan		✓	✓
Beta–glucan		✓	✓
Carboxymethylcellulose	✓		Slightly
Cellulose	✓		Slightly
Fructo-oligosaccharides, Polyfructans			✓
Galacto-oligosaccharides			✓
Guar gum		✓	✓
Hydroxypropyl methylcellulose	✓		Slightly
Inulin			✓
Methylcellulose	✓		Slightly
Oligofructose			✓
Pectin		✓	✓
Polydextrose			✓
Psyllium			✓
Resistant dextrins			✓
Resistant maltodextrins			✓
Resistant starches			✓

This chart categorizes some isolated fibers according to physiological effect. Notably, there is overlap for most fibers among the three properties.



Bulking is the process by which certain fibers increase the bulk or weight of feces. (Gray 2006; Willis and Slavin 2012) The bulking effect of dietary fibers that are poorly fermented in the colon is associated with the mass of fibers itself and enhanced in some cases by water binding, which is maintained throughout the whole gastrointestinal (GI) tract. Fermentable dietary fibers provide a bulking effect mainly due to increased bacterial mass.

Stool consistency, stool weight, and frequency of defecation are indicators of colonic function. Bulky feces moves through the gut faster, resulting in increased stool weight and improved regularity. Decreased transit time reduces contact time between the gut and potentially harmful substances in feces.

Bulking Effects of Different Fibers

Fiber Source	Feces (g)/ Fiber Fed (g)
Wheat bran	5.4
Psyllium	4.0
Cellulose	3.5
Oats	3.4
Corn	3.3
RS_3 resistant starch (e.g., wheat or high-amylose maize starch)	2.4-2.7
Legumes	2.2
Pectin	1.2
RS_2 resistant starch (e.g., green banana or raw potato)	1.0-1.7

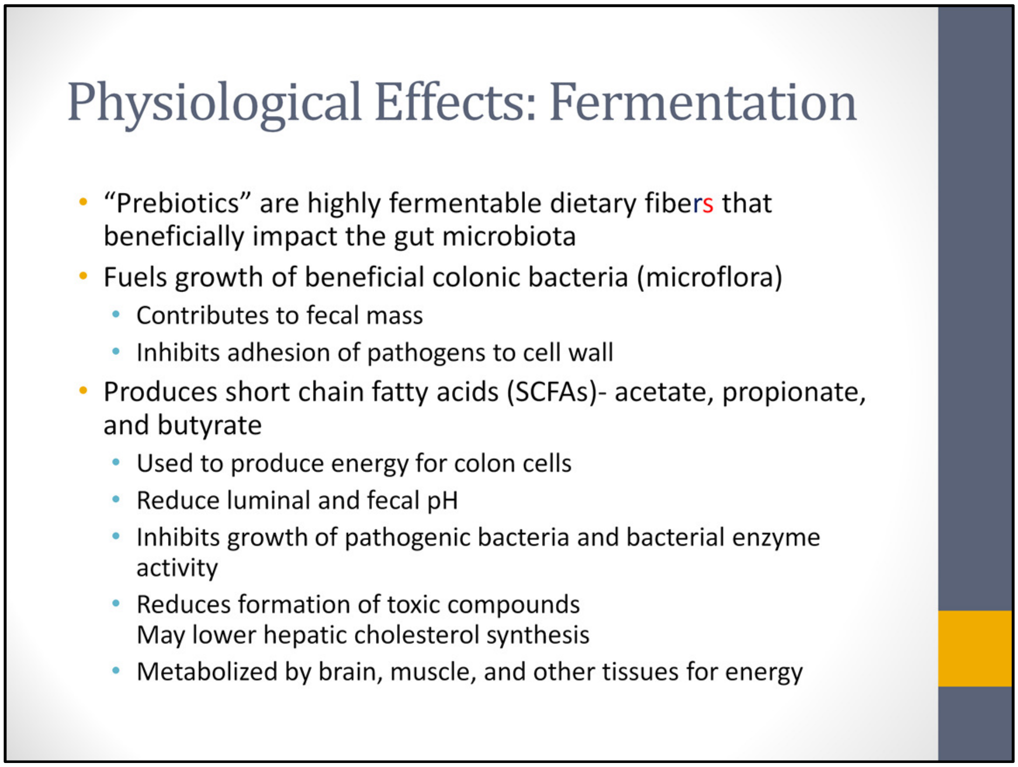
Different kinds of dietary fibers can have different bulking capacities, depending on whether they contribute directly to fecal mass and promote water binding, or do so indirectly through fermentation. This chart shows the increase in stool weight (g) with dietary fibers consumed (g). (Cummings 2001; Topping and Clifton 2001)

Both intrinsic and added fibers affect laxation, but not all are equally effective. One study demonstrated synergy between intrinsic and added fibers when subjects ate cereal products containing both. (Vuksan et al 2008) The increased dietary fibers intake was directly related to improved measures of colonic health.

Physiological Effects: Viscocity

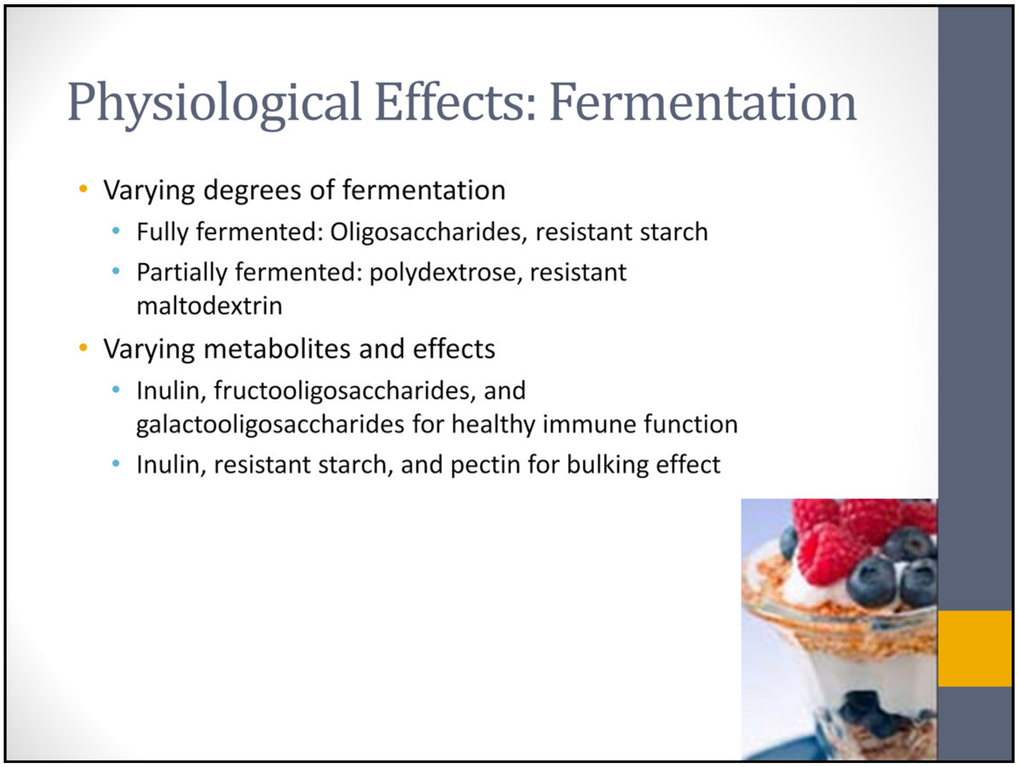
- Absorbs water and thickens contents of intestinal tract
  - Slows gastric emptying
  - Slows digestion and absorption of nutrients in small intestine
  - Binds and increases fecal excretion of bile acids, driving serum cholesterol towards bile acid production

Viscous fibers (i.e., beta-glucan and psyllium) absorb water and thicken the contents of the intestinal tract. (Slavin 2013) This slows gastric emptying, as well as digestion and the migration of nutrients such as glucose, fats, and cholesterol to the intestinal walls. Viscocity also allows fibers to bind and increase excretion of bile acids, which drives serum cholesterol towards bile acid production.



Prebiotics are dietary fibers that play an important role as a food source for microflora (bacteria) in colonic fermentation. (Slavin 2013; Gray et al 2006) The bacterial mass that results from fermentation contributes to fecal mass, as well as inhibits pathogen adhesion to the cell wall.

Healthy colonic bacteria produce, among other things, short chain fatty acids (SCFA), primarily acetate, propionate, and butyrate. Some types of fibers, such as resistant starches (RS), are particularly effective at producing specific SCFAs. (Bird et al 2010) SCFAs are used to produce energy to fuel colon cells. They reduce luminal and fecal pH, which inhibits pathogenic bacterial growth and enzymatic activity, and reduces formation of toxic compounds in the colon. SCFAs are absorbed into the body where they lower hepatic cholesterol synthesis and are metabolized by the brain, muscles, and other tissues for energy.



Different dietary fibers can be fermented to different degrees. For instance, oligosaccharides and resistant starch are fully fermented, while polydextrose and resistant maltodextrin are partially fermented. (Slavin 2013)

Fermentation variability leads to the production of different ratios of metabolites, therefore different health effects. (Slavin 2013) For example, inulin, fructooligosaccharides, and galactooligosaccharides have been shown to provide support for healthy immune function through increased levels of beneficial bacteria (e.g., *Bifidobacteria* and *Lactobacillus* species) and reduced adhesion of pathogenic bacteria to colonic cell walls. Fully fermentable fibers also contribute to bulking, with each gram of inulin, resistant starch, or pectin contributing 1.1 to 1.2 g fecal mass (see page 13).

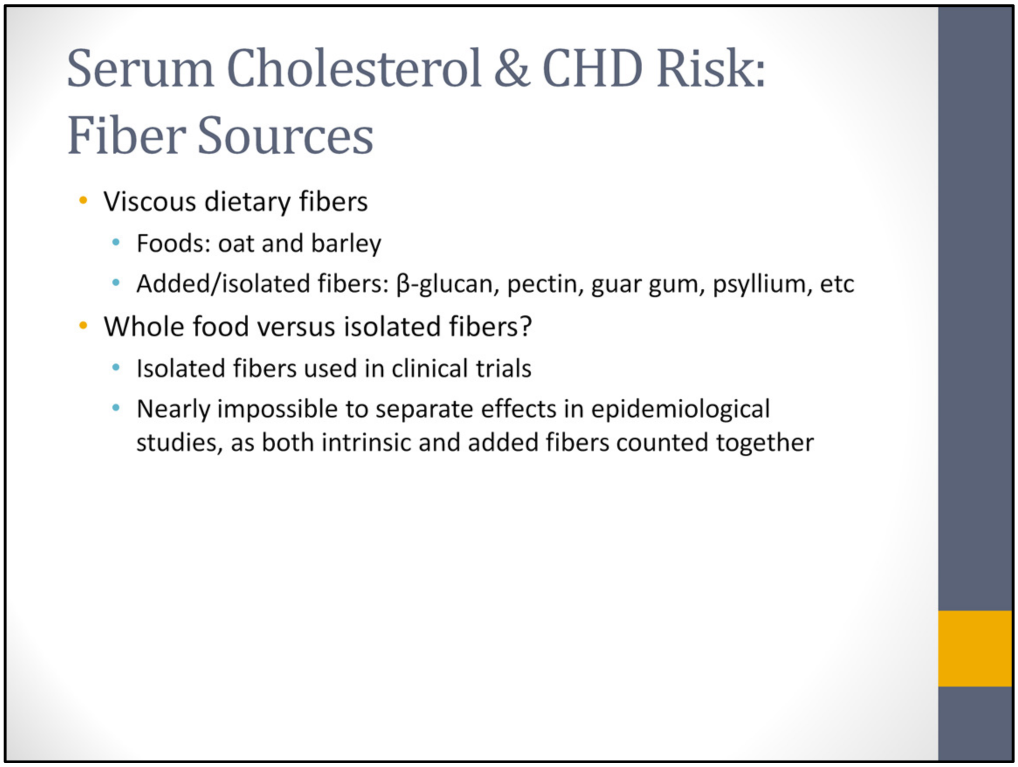
HEALTH OUTCOMES & LABEL CLAIMS

While it is important to understand the physiological impact of fibers' bulking, viscocity, and fermentation properties, evidence of fibers' impact on human health outcomes is necessary in order to inform dietary recommendations, as well as health claims on food labels.

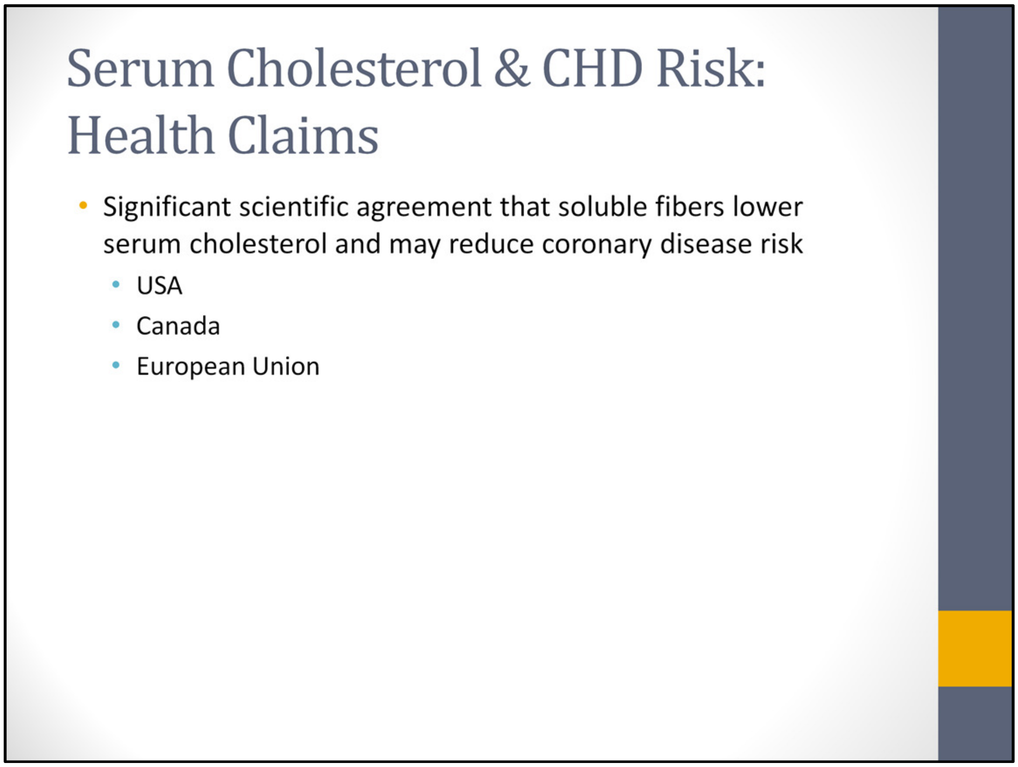
Serum Cholesterol & CHD Risk: Mechanisms of Action

- Dietary fibers bind cholesterol in small intestine, reduces absorption
- Dietary fibers bind bile acids in large intestine, redirecting serum cholesterol to synthesize bile acids
- SCFAs inhibit cholesterol synthase action in liver

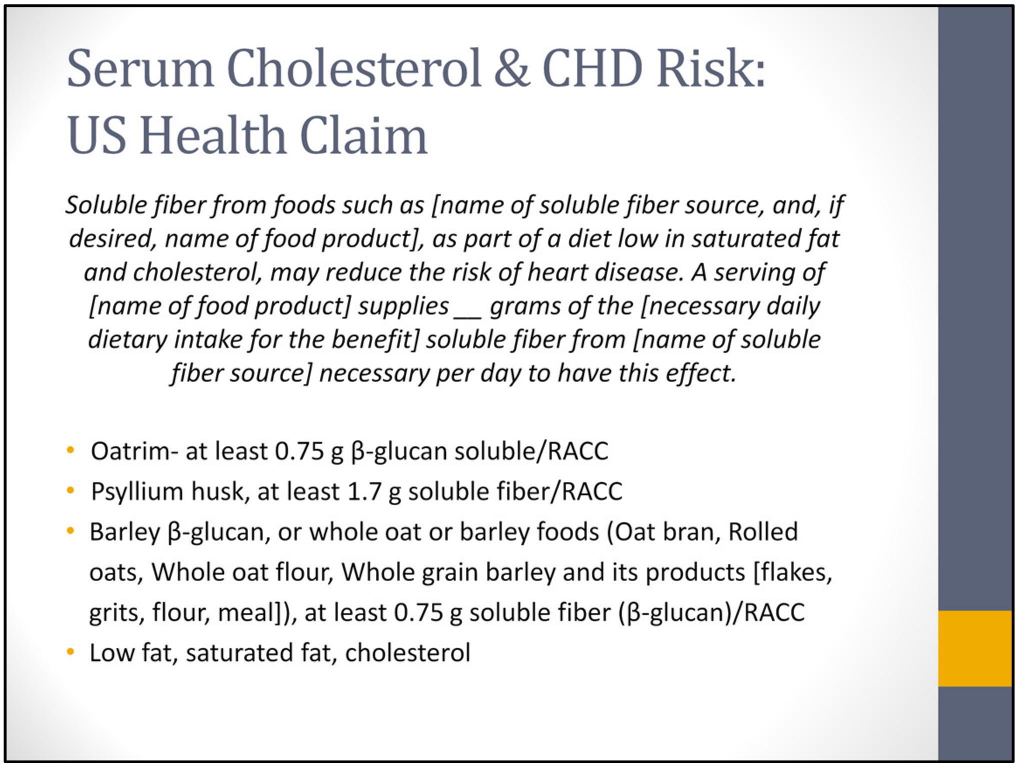
As mentioned, viscous dietary fibers trap or bind cholesterol, thereby impeding its absorption in the small intestine. In the large intestine, dietary fibers bind and hasten excretion of bile acids. The body is then required to use circulating cholesterol to synthesize needed bile acids. Fermentation of dietary fibers produces SCFA that are resorbed and transported to the liver where they can inhibit an enzyme involved in cholesterol synthesis. (Bazzano 2008; Butt et al 2007; Sartore et al 2009; Othman et al 2001; Vuksan et al 2011; Anderson et al 2009; Kendall and Jenkins 2004)



Viscous dietary fibers are found both intrinsically in foods like oat and barley, and as ingredients added to foods, such as β-glucan, pectin, guar gum, and psyllium. While intervention studies have shown that isolated viscous fibers (which are primarily soluble) improve cardiovascular disease (CVD) risk factors, epidemiological studies have found an association between ingestion of insoluble dietary fibers (primarily from wheat bran and wheat-based bread and cereal products) and lower CVD risk. (Anderson et al 2009; Ros et al 2010; Harris and Etherton 2010; Jones and Engleson 2010; Park et al 2011; Eshak et al 2010; Erkkilä and Lichtenstein 2006) One study showed that the addition of an isolated fiber (psyllium) to a diet with foods containing natural fibers, resulted in greater cholesterol lowering and a better blood lipid profile than with the high-fiber foods alone, suggesting a synergy. (Pal et al 2011) In reality, added fibers may be present and contributing to the benefits observed in epidemiological studies, but poorly documented because intrinsic versus added fibers are not distinguished in food composition databases (Dilzer et al 2013). A recent review concluded that there are benefits to high-fiber whole grain foods beyond fiber, but the health benefits of fibers for cardiovascular health are so compelling that foods with added fibers are an important option for those who do not consume sufficient whole grain foods. (Bernstein et al 20130)



There is significant scientific agreement that soluble fibers lower serum cholesterol and may reduce coronary disease risk. A number of regulatory authorities such as the US, (FDA 2014) Canada, (Health Canada 2010) and the European Commission (EFSA 2011) have health claims in this regard.

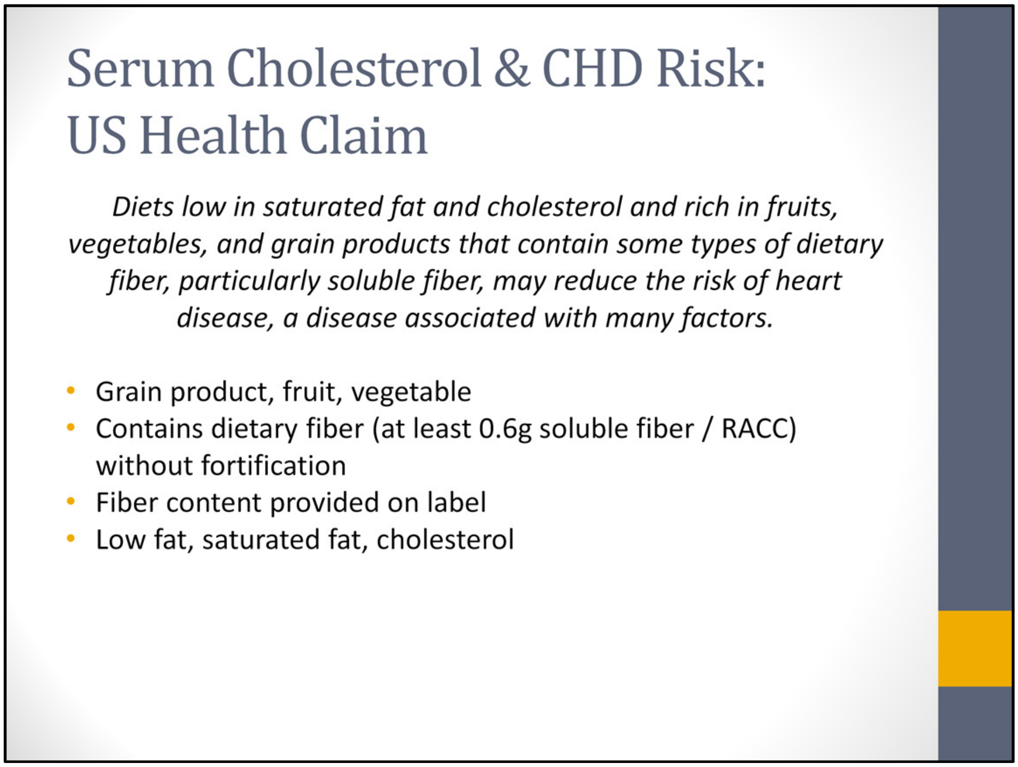


There are two US health claims for dietary fiber and CHD risk. (US FDA 2014) The first specifies soluble fiber as part of a low-fat diet:

Soluble fiber from foods such as [name of soluble fiber source, and, if desired, name of food product], as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease. A serving of [name of food product] supplies __ grams of the [necessary daily dietary intake for the benefit] soluble fiber from [name of soluble fiber source] necessary per day to have this effect.

The foods that can display this claim must be low in fat, saturated fat, and cholesterol, and contain the following dietary fibers in the specified amounts:

- Oatrim
  - at least 0.75 g β-glucan soluble /RACC
- Psyllium husk
  - at least 1.7 g soluble fiber / RACC
- Barley β-glucan, or whole oat or barley foods (Oat bran, Rolled oats, Whole oat flour, Whole grain barley and its products [flakes, grits, flour, meal]
  - at least 0.75 g soluble fiber (β-glucan) / RACC



The second US health claim for dietary fiber and CHD (US FDA 2014) emphasizes foods intrinsically high in fiber as part of a high-fiber, low-fat diet:

Diets low in saturated fat and cholesterol and rich in fruits, vegetables, and grain products that contain some types of dietary fiber, particularly soluble fiber, may reduce the risk of heart disease, a disease associated with many factors.

Foods bearing this claim must meet the following criteria:

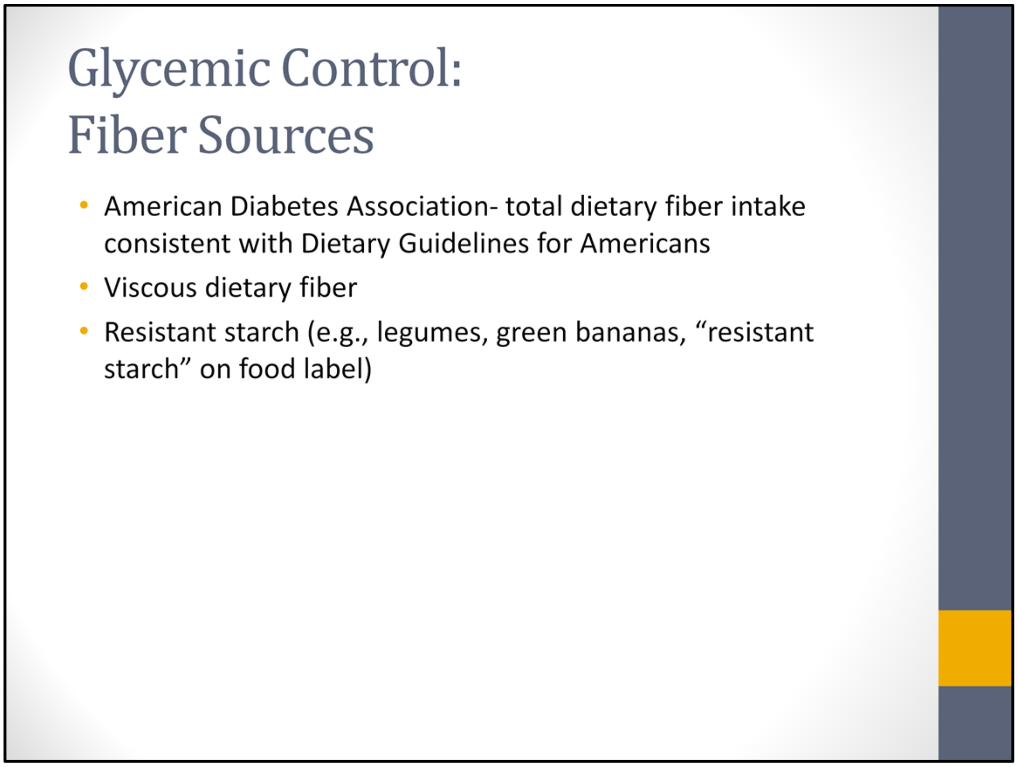
- Grain product, fruit, vegetable
- Contains at least 0.6 g soluble fiber / RACC without fortification
- Fiber content disclosed on label
- Low fat, saturated fat, cholesterol

Glycemic Control: Mechanisms of Action

- Slowed gastric emptying
- Inverse relationship between intake of fibers and glycemic parameters

Because viscous dietary fibers slow gastric emptying, they may facilitate lower caloric intake, thereby reducing risk of excess weight gain, a risk factor for diabetes. Slowed gastric emptying also slows glucose absorption. Consumption of viscous fibers is recommended by some to help control blood glucose levels in those with diabetes. (Anderson et al 2004; Anderson et al 2009)

Studies show an inverse relationship between intake of fibers and measures of post-prandial glucose response, including a flattening of the response curve and a reduction in the mean peak rise in blood glucose. (ADA 2008; Wolever and Jenkins 1993) Indeed, a number of studies have demonstrated that foods with intrinsic or added viscous fibers, as well as resistant dextrins and starches, have a beneficial effect on glycemic parameters. (Wood et al 1989; Jenkins et al 1978; Jenkins et al 2000; Livesey and Tagami 2009; Slavin et al 2009; Post et al 2012; Jenkins et al 2010; Al-Tamimi et al 2010; Babio et al 2010)

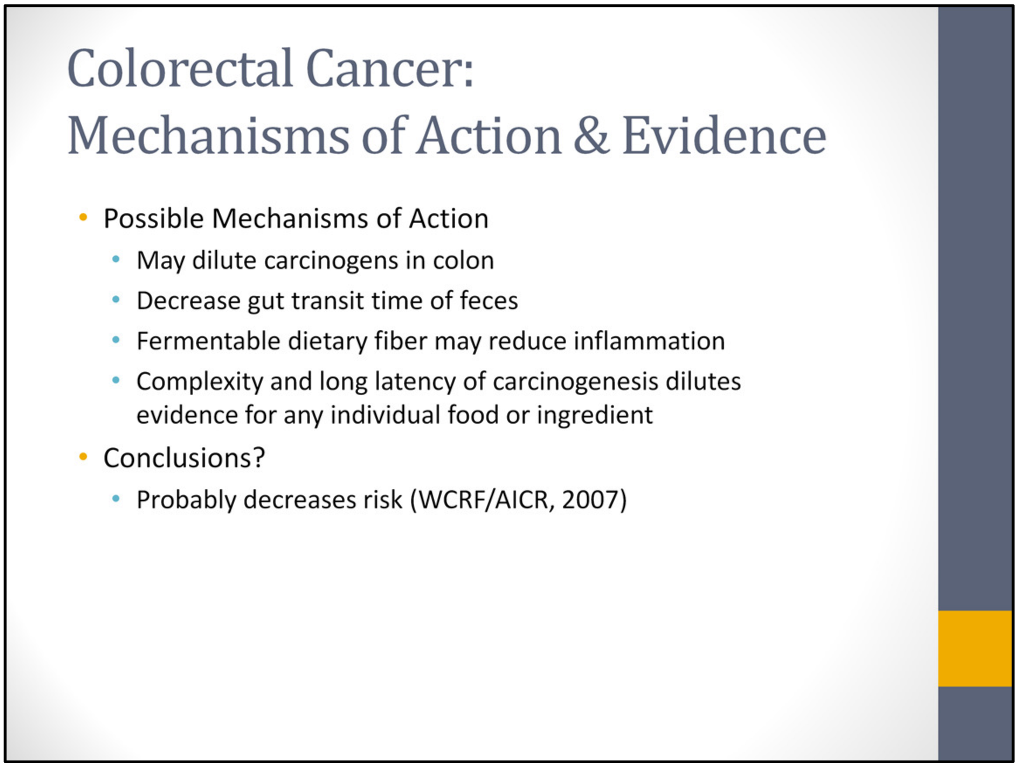


The American Diabetes Association recommends a total dietary fiber intake consistent with the Dietary Guidelines for Americans to reduce risk of type 2 diabetes and as part of a diet to manage diabetes. (ADA 2008) The sources of viscous dietary fibers have been mentioned. Resistant starches are found in legumes and green bananas, and as an ingredient in packaged foods.

Glycemic Control: EFSA Claim

- 14 g resistant starch (RS) replacing equal amount of digestible carbohydrate to reduce post-prandial glycemic response

The EFSA approved a health claim in 2012 for the replacement of digestible carbohydrate with 14 g resistant starch for the reduction of post-prandial glycemic response. (EFSA 2011)



Many mechanisms of action have suggested a potential role for dietary fiber in colorectal cancer prevention. Dietary fiber may dilute carcinogens in colon, reduce exposure time to potential carcinogens in the colon, and help to reduce inflammation. However, the complexity and long latency of carcinogenesis appear to dilute the evidence for protection by any individual food or ingredient. Still, the World Cancer Research Fund and American Institute for Cancer Research (2007) concluded that fiber probably decreases colorectal cancer risk.

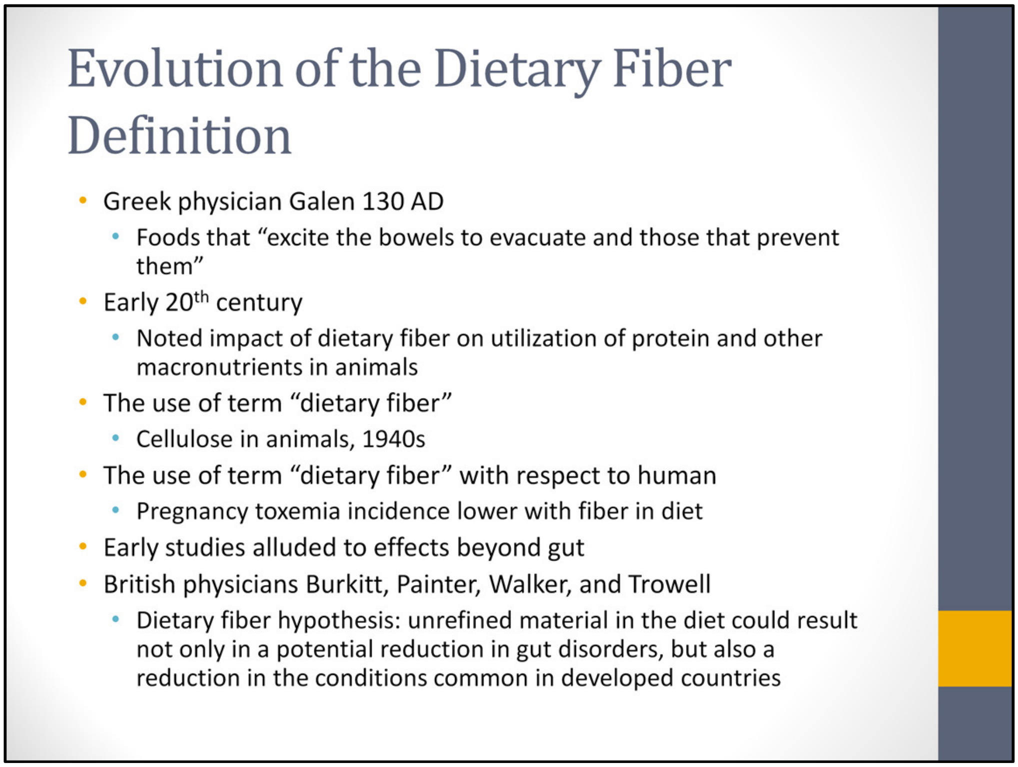
There is also a claim in the US related to foods naturally rich in fibers and reduced risk of cancer (US FDA 2014):

Low fat diets rich in fiber-containing grain products, fruits and vegetables may reduce the risk of some types of cancer, a disease associated with many factors.

Foods that bear this claim must be:

- Grain product, fruit, or vegetable
- A good source of dietary fiber (2.5g or 10% DV) without fortification
- Low fat

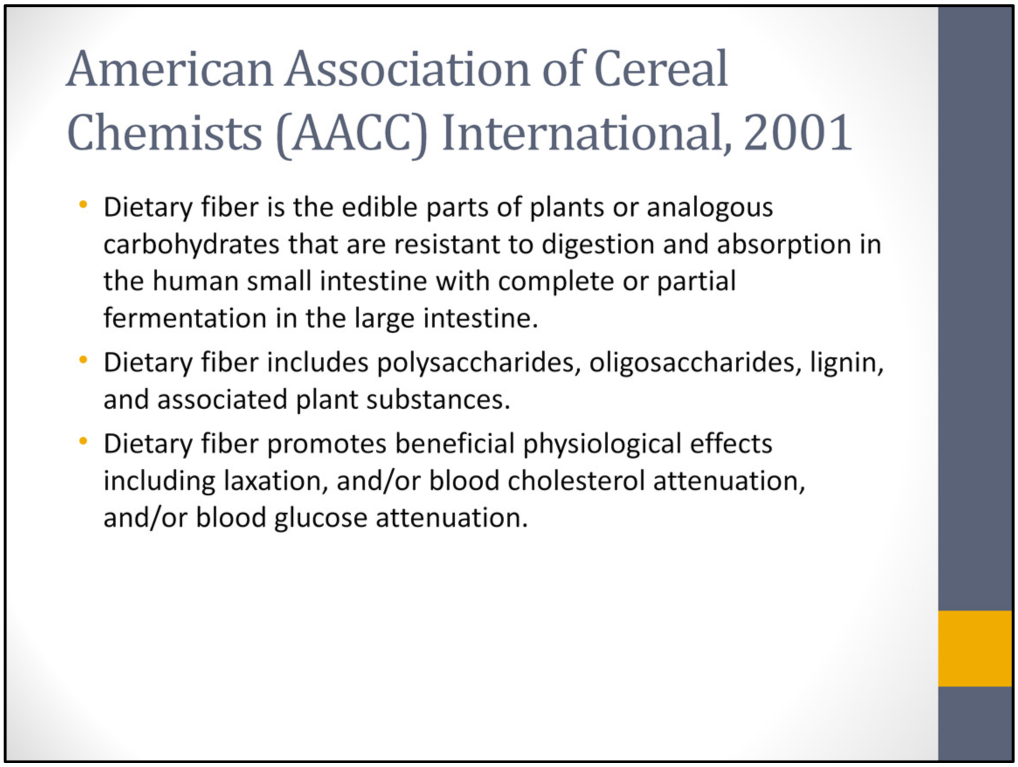
A GLOBAL SNAPSHOT OF CURRENT DIETARY FIBER DEFINITIONS



The definition of dietary fiber has evolved with evidence of its physiological and health effects. The Greek physician Galen wrote in 130 A.D. wrote about foods that "excite the bowels to evacuate and those that prevent them". (Galen 2003) He noted that white bread is "the stickiest and slowest to pass and that brown bread is good for the bowels." In the early 20th century, Mendel assessed the impact of non-digestible material on the utilization of protein and other macronutrients. (Mendel et al 1912)

The first explicit mention of dietary fiber with respect to human health was in reference to the observation that toxemia incidence was lower when foods containing dietary fiber were present in the diets of pregnant women. (Hipsley 1953) While many early studies focused on laxation, gut health, and nutrient availability, (Schmitt and Kleibel 1952; Vignec and Mitty 1952) some alluded to the potential for isolated fibers to have effects beyond the gut, such as reducing cholesterol and degree of atherosclerosis. (Duckworth and Godden 1941; Keys et al 1961)

British physicians Burkitt, Painter, Walker, and Trowell theorized that dietary fibers had health benefits beyond the gut. They noted that diseases regularly seen in Britain were rare in rural Africa and proposed that the differences were due to the unrefined nature of the African diet. Thus, in 1970 they launched the dietary fiber hypothesis, (Burkitt and Trowell 1975; Burkitt et al 1972) which suggested that unrefined material in the diet could result not only in a potential reduction in gut disorders, but also a reduction in the conditions common in developed countries, such as constipation, gallstones, diverticular disease, obesity, hiatal hernia, cancer of the large bowel, appendicitis, coronary heart disease, varicose veins, diabetes, and piles (hemorrhoids). The dietary fiber hypothesis spurred characterization of dietary fibers' diverse physiological roles and the need to refine the definition. (AACC 2001)



The American Association of Cereal Chemists (AACC) International established a definition of dietary fiber in 2001:

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 fiber promotes beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation.

Notably, all dietary fiber definitions specify that they include carbohydrates that are resistant to digestion and absorption in the small intestine. Most, but not all, specify that they must be documented as providing a physiological benefit. There is inconsistency regarding the inclusion of plant substances that are associated with fiber in food (i.e., they form a complex that is considered to work with fiber, and should therefore quantified as fiber), the inclusion of short-chain oligomers (i.e., DP < 10), and the inclusion of isolated or synthetic fibers. The AACC International definition makes no mention of the latter 2 factors.

Institute of Medicine (IOM), 2001

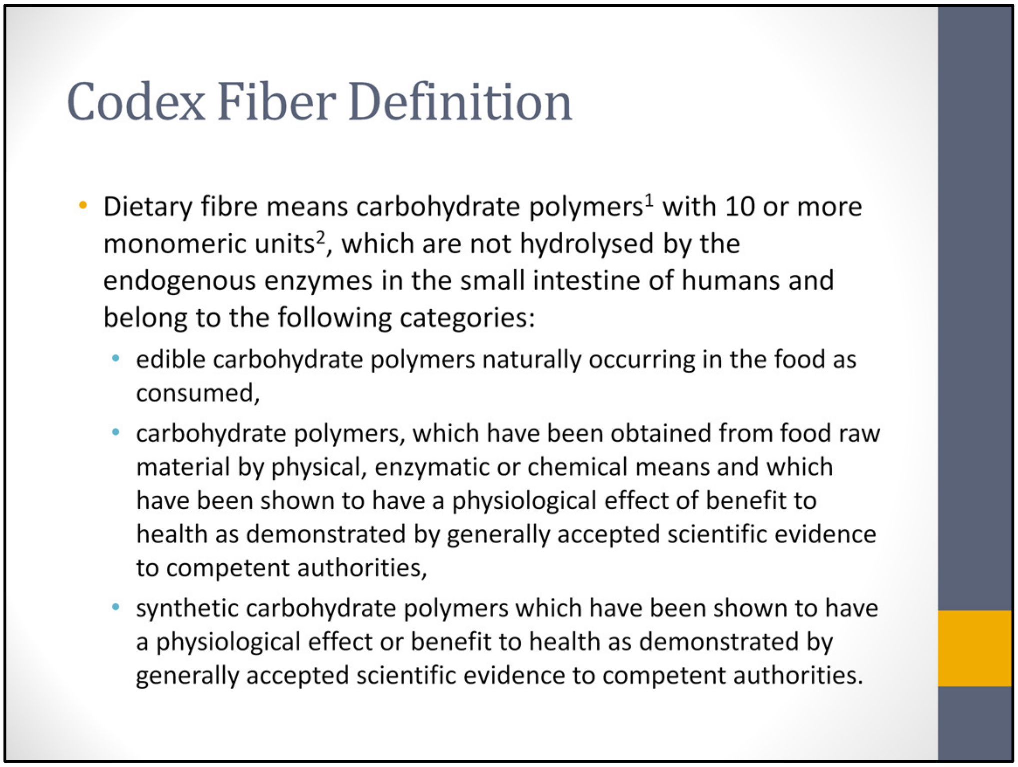
- Dietary fiber consists of non-digestible carbohydrates and lignin that are intrinsic and intact in plants.
- Functional Fiber consists of isolated, non-digestible carbohydrates with beneficial physiological effects in humans.
- Total Fiber is the sum of Dietary Fiber and Functional Fiber.

The IOM definition (IOM 2002) states:

Dietary Fiber consists of non-digestible [carbohydrates] and lignin that are intrinsic and intact in plants. Functional Fiber consists of isolated, non-digestible [carbohydrates] with beneficial physiological effects in humans. Total Fiber is the sum of Dietary Fiber and Functional Fiber.

Similar to AACC International, the IOM definition does not mention oligomer chain length. It differs from other dietary fiber definitions in that it requires that the term dietary fiber apply only to those materials that are intrinsic and intact in food. It then defines those carbohydrate materials that have isolated, modified, or synthesized and added to food as “functional fiber.” It then defines the sum of the two entities as “total fiber”. Methodologically, the IOM definition creates an analytical challenge because current analytical methods cannot distinguish between added (functional) fibers and fibers that are naturally present in the food (intrinsic). An example is a double fiber, apple-oatmeal oat bran muffin where the added (functional) beta-glucan, oat bran, and pectin are not analytically distinguishable from those compounds intrinsic to the oats, oat bran, and apple.

The distinction between added (functional) and intrinsic is not consistent with labeling of other nutrients or nutrition research. For example, the vitamin content of a food as listed on the Nutrition Facts label or in the food composition database does not differentiate whether the vitamin is naturally part of the food or whether it is part of a fortification or enrichment mixture.



Although individual countries develop their own definitions of dietary fiber, Codex, as mentioned, is intended to provide guidance to the global community to protect public health and ensure fair trade. After a 16-year process, Codex published its dietary fiber definition in 2010. (Codex 2010) It reads as follows:

Dietary fibre means carbohydrate polymers[1] with 10 or more monomeric units[2], which are not hydrolysed by the endogenous enzymes in the small intestine of humans and belong to the following categories:

- *Edible carbohydrate polymers naturally occurring in the food as consumed*
- *Carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic or chemical means and which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities*
- *Synthetic carbohydrate polymers which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities.*

Codex Fiber Definition: Strengths

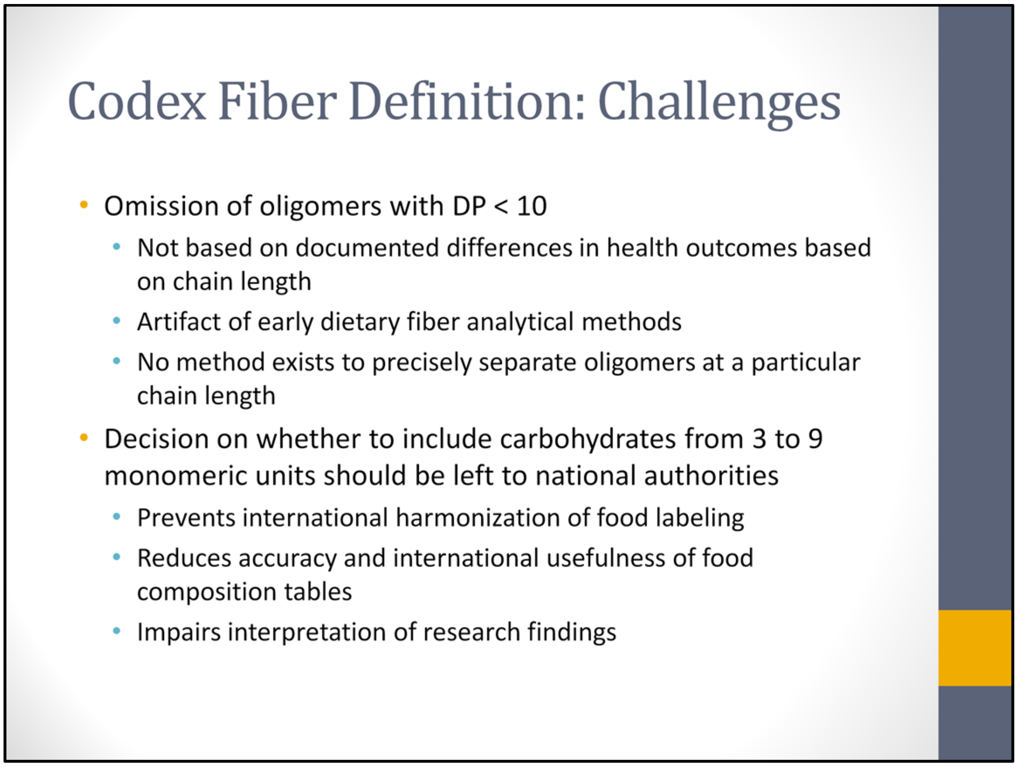
- Includes carbohydrate polymers that resist digestion or absorption in the human small intestine
- Requires at least one physiological benefit be shown
- Recognition that “associated substances” and lignin, when present in the food, may be part of the dietary fiber complex and may be measured as such

As with other definitions, Codex defines dietary fiber as polymers that resist digestion or absorption in the human small intestine.

The Codex definition, as well as many others, requires that at least one physiological benefit be shown. This is in contrast to the IOM definition that requires only functional fiber to demonstrate a physiological benefit.

Footnote #1 to the Codex Definition aligns with nearly all past definitions and recognizes that “associated substances” and lignin, when present in the food, may be part of the dietary fiber complex and may be measured as such.

When derived from a plant origin, dietary fibre 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 fibre 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 fibre insofar as they are actually associated with the poly- or oligo-saccharidic fraction of fibre. However, when extracted or even re-introduced into a food containing non digestible polysaccharides, they cannot be defined as dietary fibre. When combined with polysacchrides, these associated substances may provide additional beneficial effects (pending adoption of Section on Methods of Analysis and Sampling).



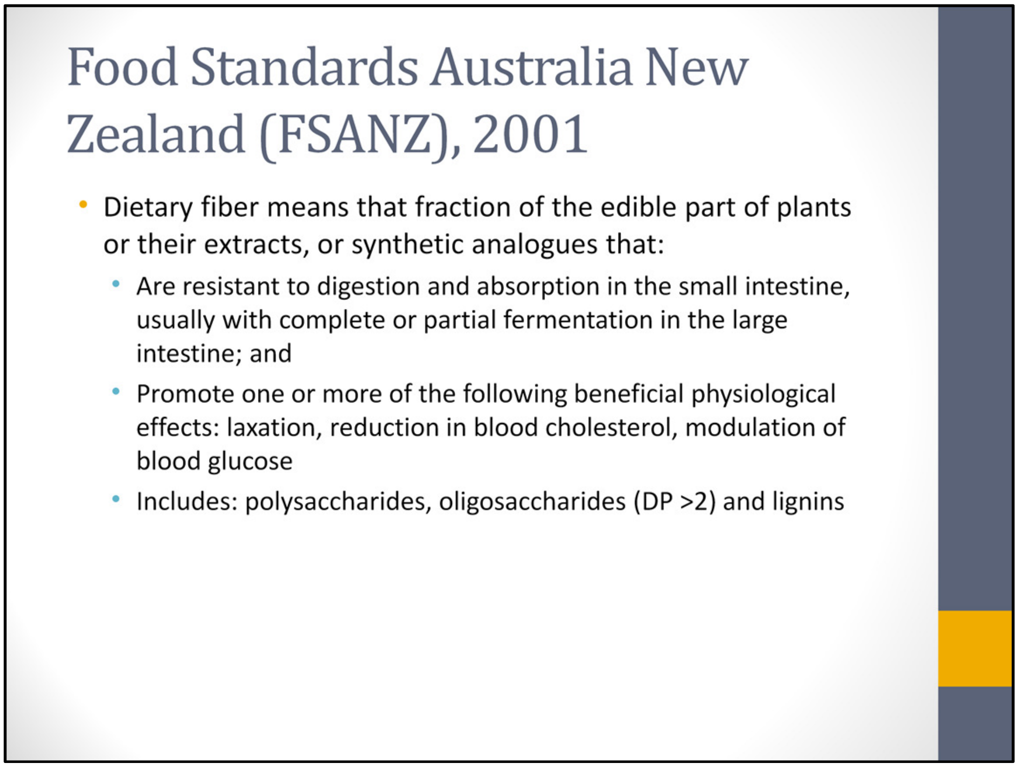
There are also challenges with the Codex definition, however.

Allowing only for oligomers with DP > 10 is not based on documented differences in health outcomes based on chain length. In fact, beneficial physiological effects have been documented (Roberfroid et al 2010; Raninen 2011; Gray 2006) for oligomers with DP 3-9. Second, the exclusion is an artifact of early dietary fiber analytical methods, in which short-chained carbohydrates (and even some materials with higher DPs) are washed into the alcohol effluent. Finally, no method exists to precisely separate oligomers at a particular chain length, e.g., at DP = 10. (Caers 2011)

However, allowing for national authorities to decide on the inclusion of oligomers with a DP 3-9 has the unfortunate consequence of allowing different operative definitions in various jurisdictions and impairing international harmonization of food labeling, food composition tables, and interpretation of research findings.

Fiber values in food composition databases and on product labels for items that contain inulin and other short-chain fructooligosaccharides, such as wheat or Jerusalem artichokes, would differ from country to country. Such inconsistencies affect the precision of food intake assessments for both nutritional care of the individual and collection of intake data at the research or national levels. Intake data is utilized in research to examine associations between food components and health outcomes or related biomarkers. Therefore the downstream effect of inconsistent definitions is a dampened ability to examine the health benefits of dietary fibers through research.

Fiber experts from around the world who attended an international Vahouny Dietary Fiber conference in 2010 voted overwhelmingly for the inclusion of all indigestible carbohydrate oligomers and polymers with DPs of 3 or higher. (Howlett et al 2010) With Canada's adoption of a new dietary fiber definition, it joins the list of countries that align their definition with Codex, and include oligomers with DP 3-9 within their definition. (Health Canada 2012) Other national authorities whose dietary fiber definition aligns with Codex and includes DP 3-9 include FSANZ (Austrlia/New Zealand), Brazil, Chile (for labeling but not health claims), China, European Commission, Indonesia, Malaysia, Mexico, and Thailand. (Jones et al 2012) In the US, the FDA designates that all nutrients should be analyzed according to acceptable AOAC methods for nutrition labeling, but does not explicitly refer to the Codex definition or acceptable oligomer chain length. (FDA 1993)

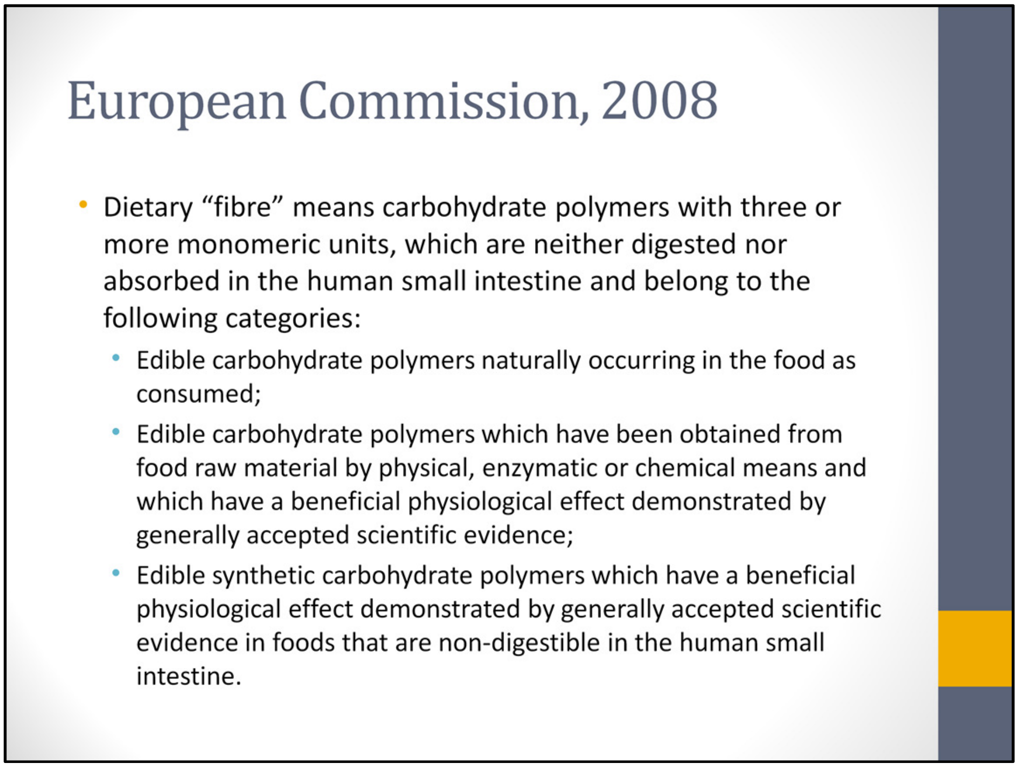


The definition adopted by Australia and New Zealand (FSANZ 2013) around the same time as the IOM (2001) published its definition follows:

Dietary fiber means that fraction of the edible part of plants or their extracts, or synthetic analogues that:

> *Are resistant to digestion and absorption in the small intestine, usually with complete or partial fermentation in the large intestine; and*
> *Promote one or more of the following beneficial physiological effects: laxation, reduction in blood cholesterol, modulation of blood glucose*
> *Includes: polysaccharides, oligosaccharides (DP >2) and lignins.*

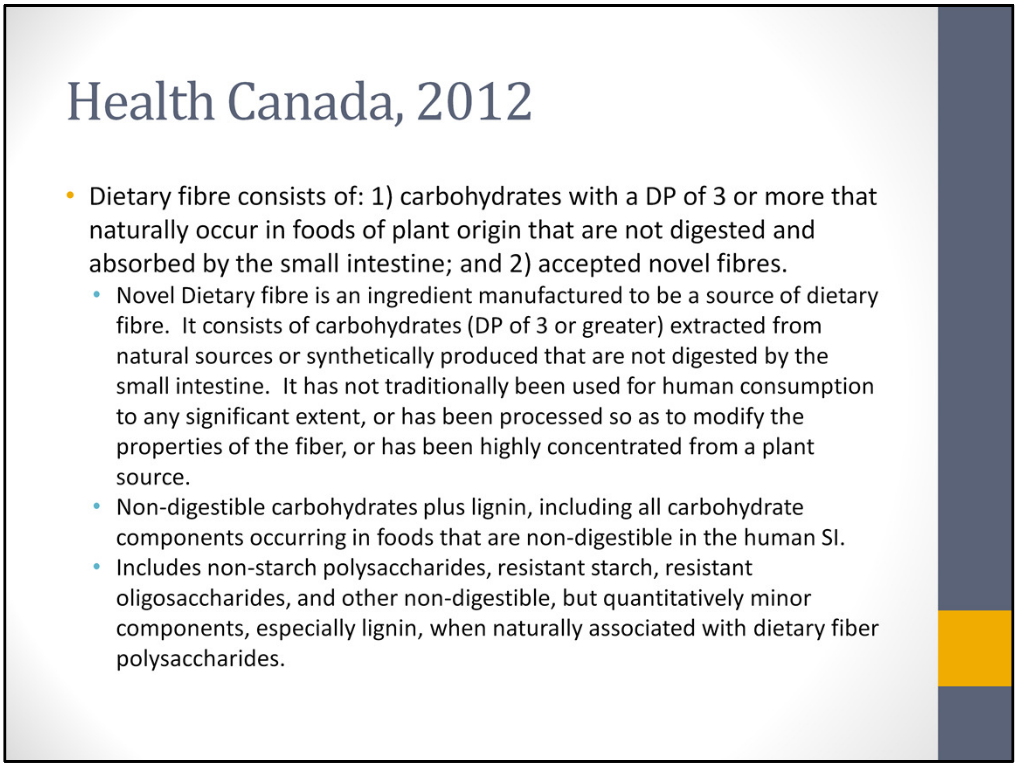
Notably, this definition is widely inclusive of both intrinsic and isolated dietary fiber, smaller DP, and lignins, and requires that all show a physiological benefit (further, specific benefits are required).



The European Commission (2008) definition is similar to Codex and other countries, except there is no mention of "associated substances":

Dietary "fibre" means carbohydrate polymers with three or more monomeric units, which are neither digested nor absorbed in the human small intestine and belong to the following categories:

- *edible carbohydrate polymers naturally occurring in the food as consumed;*
- *edible carbohydrate polymers which have been obtained from food raw material by physical, enzymatic or chemical means and which have a beneficial physiological effect demonstrated by generally accepted scientific evidence;*
- *edible synthetic carbohydrate polymers which have a beneficial physiological effect demonstrated by generally accepted scientific evidence in foods that are non-digestible in the human small intestine.*



Health Canada issued its definition in 2012, following release of the Codex definition, and is also consistent with the definitions of New Zealand, Australia, and the European Union:

Dietary fibre consists of:

1) *carbohydrates with a DP of 3 or more that naturally occur in foods of plant origin that are not digested and absorbed by the small intestine; and*
2) *accepted novel fibres.*

- *Novel Dietary fibre is an ingredient manufactured to be a source of dietary fibre. It consists of carbohydrates (DP of 3 or greater) extracted from natural sources or synthetically produced that are not digested by the small intestine. It has not traditionally been used for human consumption to any significant extent, or has been processed so as to modify the properties of the fiber, or has been highly concentrated from a plant source.*
- *Non-digestible carbohydrates plus lignin, including all carbohydrate components occurring in foods that are non-digestible in the human SI.*
- *Includes non-starch polysaccharides, resistant starch, resistant oligosaccharides, and other non-digestible, but quantitatively minor components, especially lignin, when naturally associated with dietary fiber polysaccharides.*

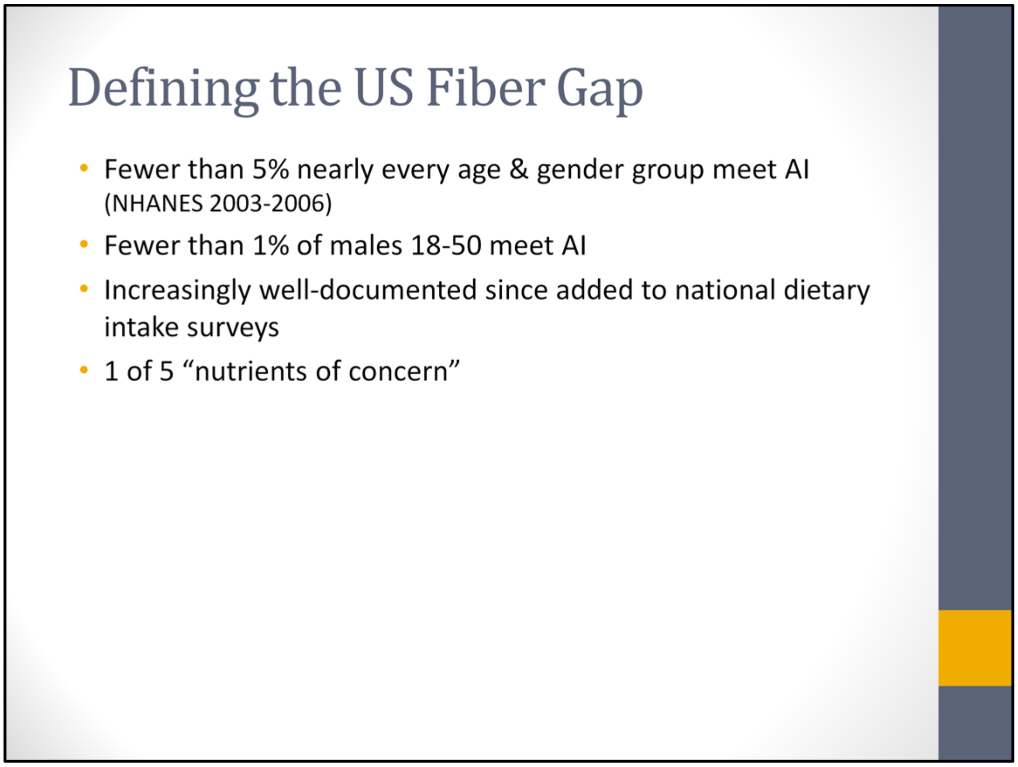
RELEVANCE OF DEFINITIONS TO THE DIETARY FIBER GAP

Global Snapshot of Recommended and Actual Intakes by Adults

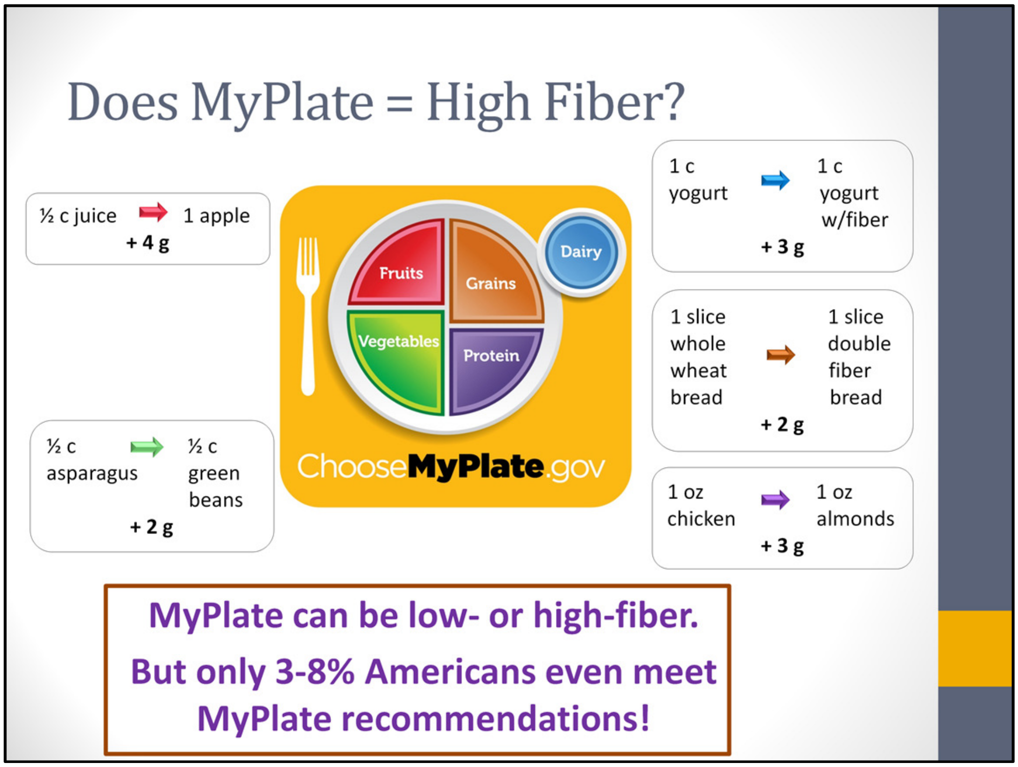
Country/ Region	Recommended Fiber Intake (g/d) for Adults (M=Male, F=Female)[1]	Estimated Fiber Intakes (g/d) for Adults (M=Male, F=Female) [2]
Health Canada and USA	38 M 25 F	18-19 M (US) 15-16 F (US)
France	25-30	21 M 20 F
Germany	30	23 M 20 F
Japan	24-27 M 19-21 F	17
UK	18 (12-24)	23 M 19 F
EFSA	25	15-30
FAO/ WHO	25	NA

[1]References: IOM, 2002; EFSA 2010; Ministry of Health, Labour and Welfare, Japan, 2005; Nishida et al 2004
[2]References: USDA WWEIA, 2009-2010; EFSA 2010; Murphy et al 2012; Gray et al 2006

This chart provides a global snapshot of fiber intake recommendations (IOM, 2002; EFSA 2010; Ministry of Health, Labour and Welfare, Japan, 2005; Nishida et al 2004) and actual intakes (USDA WWEIA, 2009-2010; Health Canada 2004; EFSA 2010; Murphy et al 2012; Gray et al 2006) by adults around the globe. Clearly, there is a gap between recommended and actual intakes.

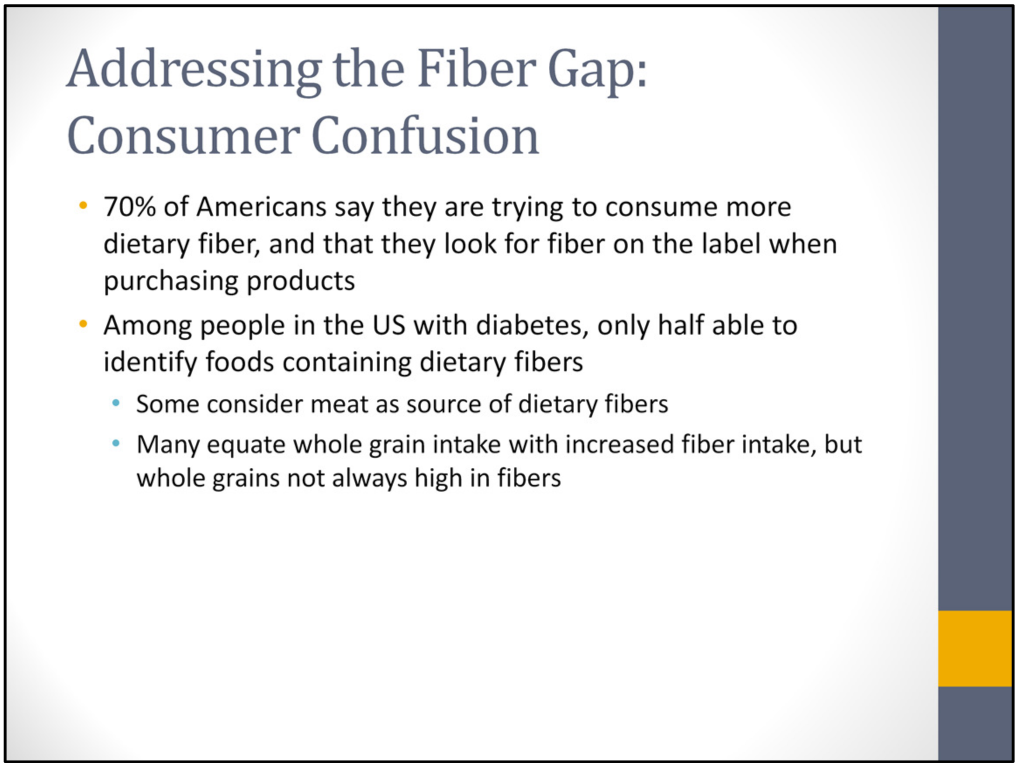


An analysis by Marriott and colleagues (2010) found that fewer than 5 percent of the US population in nearly every NHANES age and gender subgroup met the AI for dietary fiber in 2003 to 2006. Fewer than 1 percent of males 18 to 50 years met the AI. Poor intake of dietary fibers is unfortunately not new, but has been more well-documented since it was added as a compound to assess in national dietary intake surveys. (Lanza et al 1987) Intakes of dietary fibers are far from optimal. In fact, they are so poor that the Dietary Guidelines for Americans 2010 listed dietary fiber as one of five ”nutrients of concern.” (USDA and HHS 2010) Such a designation denotes that a large segment of the US population does not consume enough of this essential dietary component.



MyPlate can be either low- or high-fiber with a few tweaks. Careful adherence to the federal food guidance system, MyPlate, would mean adequate consumption of fiber-rich foods through whole grains (wheat, maize, oats, rye, barley, triticale, millet, sorghum, buckwheat, etc), legumes (including soy), fruits, vegetables, nuts, and seeds. In fact, Dilzer and colleagues (2013) noted that with high-fiber choices from each MyPlate food group, it is possible to get 59 g/d of dietary fiber. As an example on this slide, switching from a low fiber to a high fiber choice for just one serving from each of the food groups can increase fiber intake by a total of 14 g/d.

However, only three to eight percent of Americans even meet MyPlate recommendations. (Krebs-Smith et al 2010; USDA and HHS 2010) The US per capita consumption fails to reach even one-half a serving of legumes per week. (Busby 2008) Fewer than 1 in 10 meet the whole grain requirement. (USDA and HHS 2010) Fruit and vegetable selections are often iceberg lettuce and other lower fiber options. (Busby 2008)



Despite low intakes, 62% of Americans surveyed say that they are trying to get as much dietary fiber as possible, and 68% said that they look for fibers on the label when purchasing products. (IFIC 2013) One barrier to success is a lack of understanding of where to find fibers. (Obayashi et al 2003) In a survey of people in the US with diabetes (a population that often has higher nutrition knowledge than other subsets), only half of the participants were able to identify foods containing dietary fibers. (Kessler et al 1999) Another survey showed that some subjects considered meat to be a source of dietary fibers, since they could ”see” the muscle fibers. (Kellogg Company 2009) Many equate whole grain intake with increased fiber intake, but not all whole grains are high in fibers.

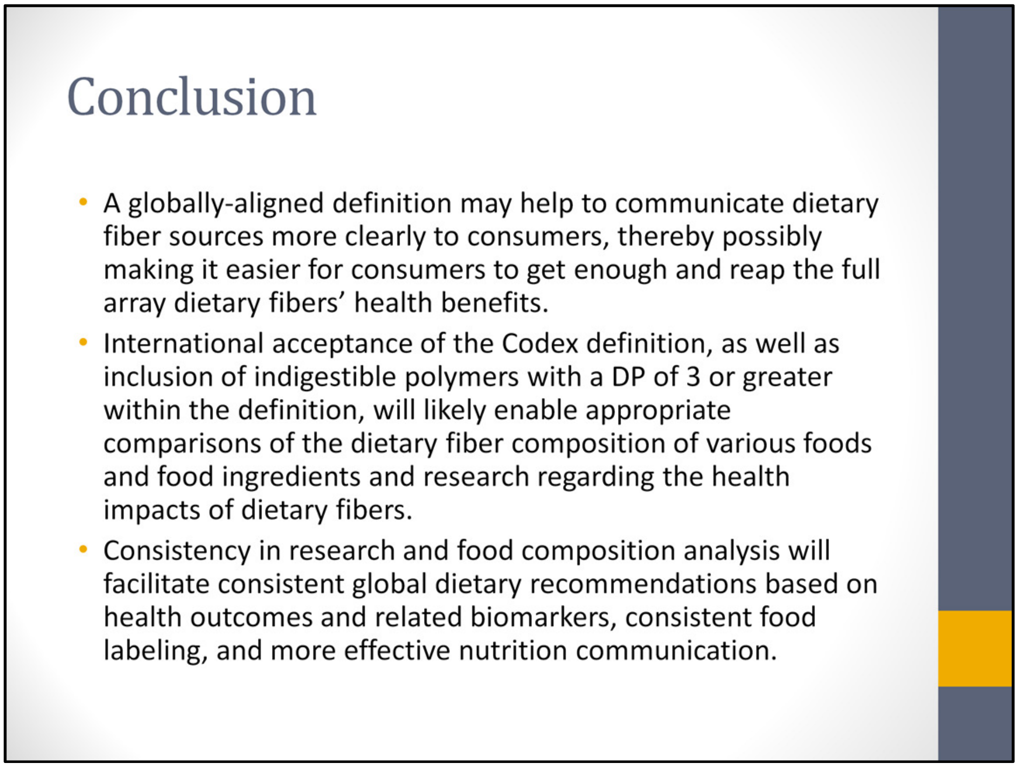
Average Fiber Content of Various Whole Grains

Serving size (g)	Fiber per Serving (g)				
	Brown Rice	Whole Grain Corn Meal	Whole Oats	Whole Grain Wheat	Barley
100	1.8	7.3	10.3	12.2	13.7
55	1.0	3.6	5.7	6.7	7.5
30	0.5	2.2	3.1	3.7	4.1

The effort to include whole grains may actually reduce fiber intake if items like high-fiber bran cereals are replaced with lower fiber varieties of whole grain cereals. (Kellogg Company 2009; Nordström and Thunström 2009) Whole grains, of course, contribute many nutrients and other phytonutrients to the diet beyond fiber. However, the benefits of both intrinsic and added fibers are well-documented, (Willis et al 2009; Pal et al 2011; Post et al 2012) and it is important for individuals to consume adequate fiber, as well as whole grains.

There may be an advantage of increasing the fiber content of commonly consumed foods so that fiber levels can increase without increasing calories. For example, the addition of oat bran and β-glucan to a serving of oatmeal can give the cholesterol-lowering dose of fiber with less than half the calories than if the β-glucan came from oatmeal without added fiber. (Davidson et al 1991)

Whether intrinsic or added, total dietary fiber is an important dietary goal that may have positive impacts on satiety, gut health, heart health, glycemic control, and reducing risk for certain cancers.



A globally-aligned definition may help to communicate dietary fiber sources more clearly to consumers, thereby possibly making it easier for consumers to get enough and reap the full array dietary fibers' health benefits.

International acceptance of the Codex definition, as well as inclusion of indigestible polymers with a DP of 3 or greater within the definition, will likely enable appropriate comparisons of the dietary fiber composition of various foods and food ingredients and research regarding the health impacts of dietary fibers.

Consistency in research and food composition analysis will facilitate consistent global dietary recommendations based on health outcomes and related biomarkers, consistent food labeling, and more effective nutrition communication.

Conclusion

- Dietary fiber is a nutrient of concern in most countries. Thus, efforts must continue to urge consumers to increase their intake of fiber.
- Natural foods are a mix of dietary fiber types, and like each individual vitamin, each entity performs some unique and some overlapping functions in comparison with other fibers. Thus, it is important to ingest the many different types of dietary fibers from both fiber-fortified foods and fiber-rich foods.

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Natural foods are a mix of dietary fiber types, and like each individual vitamin, each entity performs some unique and some overlapping functions in comparison with other fibers. Thus, it is important to ingest the many different types of dietary fibers. Both fiber-fortified foods and fiber-rich foods are important sources of these many types of fibers . This two-pronged strategy ensures that the associated substances that are trapped in the fiber matrix of natural foods are part of the diet, facilitates consumption of a variety of dietary fibers at sufficient levels to meet the fiber requirement, and helps individuals to avoid exceeding caloric needs in the quest for fiber.

References

Al-Tamimi EK, Seib PA, Snyder BS, Haub MD. Consumption of cross-linked resistant starch (RS4(XL)) on glucose and insulin responses in humans. *J Nutr Metab*. 2010;pii:651063.

American Association of Cereal Chemists (AACC). The definition of dietary fiber: Report of the Dietary Fiber Definition Committee to the Board of Directors of the AACC. *Cereal Foods World*. 2001;46:112-26.

American Diabetes Association. Nutrition recommendations and interventions for diabetes-2008. A position statement of the American Diabetes Association. *Diabetes Care*. 2008;31:S61-78.

Anderson JW, Baird P, Davis RH Jr, et al. Health benefits of dietary fiber. *Nutr Rev*. 2009;67:188-205.

Anderson JW, Randles KM, Kendall CW, Jenkins, DJ. Carbohydrate and fiber recommendations for individuals with diabetes: A quantitative assessment and meta-analysis of the evidence. *J Am Coll Nutr*. 2004;23:5-17.

Aune D, Chan DS, Greenwood DC, et al. Dietary fiber and breast cancer risk: a systematic review and meta-analysis of prospective studies. *Ann Oncol*. 2012;23:1394-402.

Aune D, Chan DS, Lau R, et al. Dietary fibre, whole grains, and risk of colorectal cancer: systematic review and dose-response meta-analysis of prospective studies. *BMJ.* 2011;343:d6617.

Babio N, Balanza R, Basulto J, et al. Dietary fibre: influence on body weight, glycemic control and plasma cholesterol profile. *Nutr Hosp.* 2010;25:327-40.

Bajorek SA, Morello CM. Effects of dietary fiber and low glycemic index diet on glucose control in subjects with type 2 diabetes mellitus. *Ann Pharmacother.* 2010;44:1786-92.

Bazzano L. Effects of soluble dietary fiber on low-density lipoprotein cholesterol and coronary heart disease risk. *Curr Atheroscler Rep*. 2008;10:473-7.

Bernstein AM, Titgemeier B, Kirkpatrick K, et al. Major cereal grain fibers and psyllium in relation to cardiovascular health. *Nutrients*. 2013;5:1471-87.

Bird AR, Conlon MA, Christophersen CT, Topping D. Resistant starch, large bowel fermentation and a broader perspective of prebiotics and probiotics. *Benef Microbes.* 2010;1:423-31.

Brennan CS. Dietary fibre, glycaemic response, and diabetes. *Mol Nutr Food Res.* 2005;49:560-70.

Burkitt DP, Trowell HC eds. Refined Carbohydrate Foods and Disease: Some Implications of Dietary Fibre. Academic Press, London: 1975.

Burkitt DP, Walker AR, Painter NS. Effect of dietary fibre on stools and the transit-times, and its role in the causation of disease. *Lancet.* 1972;2:1408-12.

References

Butt MS, Shahzadi N, Sharif MK, Nasir M. Guar gum: a miracle therapy for hypercholesterolemia, hyperglycemia and obesity. *Crit Rev Food Sci Nutr.* 2007;47:389-96.

Caers, W. Oligosaccharides: Its Commercial Application as Dietary Fibres and Prebiotics. Dietary Fibre and Prebiotics: Science and Regulatory Update. ILSI SE Asia and Nutrition Society of Thailand Annual meeting. Bangkok. April 25, 2011.

Chearskul S, Sangurai S, Nitiyanant W, et al. Glycemic and lipid responses to glucomannan in Thais with type 2 diabetes mellitus. *J Med Assoc* 2007;90:2150-7.

Chen GC, Lv DB, Pang Z, et al. Dietary fiber intake and stroke risk: a meta-analysis of prospective cohort studies. *Eur J Clin Nutr.* 2013;67:96-100.

CODEX Alimentarius (CODEX). Guidelines on Nutrition Labeling, CAC/GL 2-1985. Last amended 2013. Available at: https://www.google.com/url?q=http://www.codexalimentarius.org/input/download/standards/34/CXG_002e.pdf&sa=U&ei=y2sDU6ILp9fIAevygfAH&ved=0CAUQFjAA&client=internal-uds-cse&usg=AFQjCNH6DmEgxDJvDmwpKIJb2m0L568TgQ. Accessed February 18, 2014.

Coleman HG, Murray LJ, Hicks B, et al. Dietary fiber and the risk of precancerous lesions and cancer of the esophagus: a systematic review and meta-analysis. *Nutr Rev.* 2013;71:474-82.

Conterno L, Fava F, Viola R, Tuohy KM. Obesity and the gut microbiota: does up-regulating colonic fermentation protect against obesity and metabolic disease? *Genes Nutr.* 2011;6:241-60.

Cummings, JH. The effect of dietary fiber on fecal weight and composition. In Spiller G (ed): Dietary Fiber in Human Nutrition. CRC Press, Boca Raton (FL): 2001.

Davidson MH, Dugan LD, Burns JH, et al. The hypercholesterolemic effects of beta-glucan in oatmeal and oat bran. A dose-controlled study. *JAMA.* 1991;265:1833-9.

De Preter V, Hamer HM, Windey K, Verbeke K. The impact of pre- and/or probiotics on human colonic metabolism: does it affect human health? *Mol Nutr Food Res.* 2011;55:46-57.

Dilzer A, Jones JM, Latulippe M. The family of dietary fibers: dietary variety for maximum health benefit. *Nutr Today.* 2013;48:108-18.

Duckworth J, Godden WJ. The influence of dietary fibre on secretory activities of the alimentary tract: observations on faecal phosphatase excretion and calcium and nitrogen balances of rats. *Biochem J.* 1941;35:16-23.

European Commission (EC). 2008 Commission Directive 2008/100/EC of 28 October 2008 amending Council Directive 90/496/EEC. Official Journal of the European Union. 2008. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2008:285:0009:0012:EN:PDF. Accessed February 18, 2014.

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA): Scientific Opinion on the substantiation of a health claim related to barley beta-glucan and lowering of blood cholesterol and reduced risk of (coronary) heart disease pursuant to Article 14 of Regulation (EC) No 1924/2006. *EFSA Journal.* 2011;9:2470-84.

References

EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA); Scientific Opinion on the substantiation of health claims related to resistant starch and reduction of post-prandial glycaemic responses (ID 681),“digestive health benefits” (ID 682) and “favours a normal colon metabolism” (ID 783) pursuant to Article 13(1) of Regulation (EC) No 1924/2006. *EFSA Journal.* 2011;9:2024-41.

EFSA Panel on Dietetic Products, Nutrition, and Allergies (NDA). Scientific Opinion on Dietary Reference Values for carbohydrates and dietary fibre. *EFSA Journal.* 2010;8:1462.

El Khoury D, Cuda C, Luhovyy BL, Anderson GH: Beta glucan: health benefits in obesity and metabolic syndrome. *J Nutr Metab.* 2012:851362.

Erkkilä AT, Lichtenstein AH. Fiber and cardiovascular disease risk: how strong is the evidence? *J Cardiovasc Nurs.* 2006;21:3-8.

Eshak ES, Iso H, Date C, et al. JACC Study Group: Dietary fiber intake is associated with reduced risk of mortality from cardiovascular disease among Japanese men and women. *J Nutr.* 2010;140:1445-53.

Food Standards Australia New Zealand (FSANZ). Australia New Zealand Food Standards Code - Standard 1.2.8 - Nutrition Information Requirements. Prepared 18 January 2013. Available at: http://www.comlaw.gov.au/Details/F2013C00098. Accessed December 13, 2013.

Galen. In “On the Properties of Foodstuffs,” Translated by O Powell. Cambridge University Press, Cambridge (UK): 2003.

Galisteo M, Duarte J, Zarzuelo A. Effects of dietary fibers on disturbances clustered in the metabolic syndrome. *J Nutr Biochem.* 2008;19:71-84.

Gray J. “Dietary Fibre: Definition, Analysis, Physiology & Health.” ILSI Europe, Brussels: 2006.

Harris KA, Kris-Etherton PM. Effects of whole grains on coronary heart disease risk. *Curr Atheroscler Rep.* 2010;12:368-76.

Health Canada. Bureau of Nutritional Sciences Food Directorate, Health Products and Food Branch: Policy for Labelling and Advertising of Dietary Fibre-Containing Food Products. Available at: http://www.hc-sc.gc.ca/fn-an/legislation/pol/fibre-label-etiquetage-eng.php. Accessed January 30, 2014.

Health Canada. Canadian community health survey, cycle 2.2, nutrition: income-related household food security in Canada. 2004. http://www.hc-sc.gc.ca/fn-an/surveill/nutrition/commun/supp_table_tableau-eng.php. Accessed January 30, 2014.

Health Canada: Summary of Assessment of a Health Claim about Oat Products and Blood Cholesterol Lowering. 2010. http://www.hc-sc.gc.ca/fn-an/label-etiquet/claims-reclam/assess-evalu/oat-avoine-eng.php. Accessed January 30, 2014.

Hipsley EH. Dietary "fibre" and pregnancy toxaemia. *Br Med J.* 1953;2:420-2.

References

Howlett JF, Betteridge VA, Champ M, et al. The definition of dietary fiber – discussions at the ninth Vahouny fiber symposium: building scientific agreement. *Food & Nutrition Research.* 2010;54:1-5.

International Food Information Council (IFIC). 2013 Food & Health Survey. Available at: http://www.foodinsight.org/LinkClick.aspx?fileticket=spavtJtVkzM%3d&tabid=1482. Accessed January 30, 2014.

Institute of Medicine (IOM), The National Academies of Science (NAS). Dietary Reference Intakes for Energy, Carbohydrate, Fiber, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. The National Academies Press, Washington (DC): 2002.

IOM, NAS. Dietary Reference Intakes: Proposed Definition of Dietary Fiber. The National Academies Press, Washington (DC): 2001.

Jenkins AL, Kacinik V, Lyon M, Wolever TM. Effect of adding the novel fiber, PGX®, to commonly consumed foods on glycemic response, glycemic index and GRIP: a simple and effective strategy for reducing post prandial blood glucose levels--a randomized, controlled trial. *Nutr J.* 2010;9:58.

Jenkins DJ, Kendall CW, Axelsen M, et al. Viscous and nonviscous fibres, nonabsorbable and low glycaemic index carbohydrates, blood lipids and coronary heart disease. *Curr Opin Lipidol.* 2000;11:49-56.

Jenkins DJA, Wolever TMA, Leeds AR, et al. Dietary fibres, fibre analogues and glucose tolerance: importance of viscosity. *BMJ.* 1978;1:1392-4.

Jones JM. Dietary fiber definitions and methods- A short history. Presentation to ILSI North America Annual Meeting, Carbohydrates Forum. January 2012. Available at: http://www.ilsi.org/Documents/2012%20AM%20Presentations/Jones.pdf. Accessed January 10, 2014.

Jones JM, Engleson J. Whole grains: benefits and challenges. *Annu Rev Food Sci Technol.* 2010;1:19-40.

Kellogg Co: "Americans may be looking to the wrong foods to boost their fiber intake, research reveals." Kellogg Company's Whole Grains & Fiber Omnibus Survey, 2009. Accessed February 27, 2012.

Kendall CW, Jenkins D. A dietary portfolio: maximal reduction of low-density lipoprotein cholesterol with diet. *Curr Atheroscler Rep.* 2004;6:492-8.

Kessler K, Wunderlich SM: Relationship between use of food labels and nutrition knowledge of people with diabetes. *Diabetes Educ.* 1999;25:549–559.

Keys A, Grande F, Anderson JT. Fiber and pectin in the diet and serum cholesterol concentration in man. *Proc Soc Exp Biol Med.* 1961;106:555-8.

Kranz S, Brauchla M, Slavin JL, Miller KB. What Do We Know about Dietary Fiber Intake in Children and Health? The Effects of Fiber Intake on Constipation, Obesity, and Diabetes in Children. *Adv Nutr.* 2012;3:47-53.

References

Krebs-Smith SM, Guenther PM, Subar AF, et al. Americans do not meet federal dietary recommendations. *J Nutr.* 2010;140:1832-8.

Lanigan J, Turnbull B, Singhal A. Toddler diets in the UK: deficiencies and imbalances. 2. Relationship of toddler diet to later health. *J Fam Health Care.* 2007;17:197-200.

Lanza E, Jones DY, Block G, Kessler L. Dietary fiber intake in the US population. *Am J Clin Nutr.* 1987;46:790–797.

Livesey G, Tagami H. Interventions to lower the glycemic response to carbohydrate foods with a low-viscosity fiber (resistant maltodextrin): meta-analysis of randomized controlled trials. *Am J Clin Nutr.* 2009;89:114-25.

Macfarlane GT, Macfarlane S. Fermentation in the human large intestine: its physiologic consequences and the potential contribution of prebiotics. *J Clin Gastroenterol.* 2001;45 Suppl:S120-7.

Marriott BP, Olsho L, Hadden L, Connor P. Intake of added sugars and selected nutrients in the United States, National Health and Nutrition Examination Survey (NHANES) 2003—2006. *Crit Rev Food Sci Nutr.* 2010;50:228-58.

McCleary BV. An integrated procedure for the measurement of total dietary fibre (including resistant starch), non-digestible oligosaccharides and available carbohydrates. *Anal Bioanal Chem.* 2007;389:291-308.

McKeown NM, Meigs JB, Liu S, et al. Carbohydrate nutrition, insulin resistance, and the prevalence of the MetS in the Framingham Offspring Cohort. *Diabetes Care.* 2004;27:538-46.

McKeown NM, Yoshida M, Shea MK, et al. Whole-grain intake and cereal fiber are associated with lower abdominal adiposity in older adults. *J Nutr.* 2009;139:1950-5.

Mendel LB, Fine, MS. Studies in nutrition. IV. The utilization of the proteins of the legumes. *J Biochem.* 912;11:433-60.

Ministry of Health, Labour and Welfare, Japan. Dietary Reference Intakes for Japanese. 2005. Available at: http://www0.nih.go.jp/eiken/english/research/pdf/dris2005_eng.pdf. Accessed December 13, 2013.

Mugie SM, Di Lorenzo C, Benninga MA: Epidemiology of constipation in children and adults: a systematic review. *Best Pract Res Clin Gastroenterol.* 2011;25:3-18.

Murphy N, Norat T, Ferrari P, et al. Dietary fibre intake and risks of cancers of the colon and rectum in the European prospective investigation into cancer and nutrition (EPIC). *PLoS One*. 2012;7:e39361.

References

Nishida C, Uauy R, Kumanyika S, Shetty P. Joint FAO/WHO Expert Consultation: Carbohydrates in human nutrition. *Public Health Nutr.* 2004;7:245-250.

Nordström J, Thunström L. The impact of tax reforms designed to encourage healthier grain consumption. *J Health Econ.* 2009;28:622-34.

Obayashi S, Bianshi LJ, Song WO. Reliability and validity of nutrition knowledge, social-psychological factors, and food label use scales from the 1995 Diet and Health Knowledge Survey. *J Nutr Educ Behav.* 2003;35:83-91.

Othman RA, Moghadasian MH, Jones PJ. Cholesterol-lowering effects of oat β-glucan. *Nutr Rev.* 2001;69:299-309.

Pal S, Khossousi A, Binns C, et al. The effect of a fibre supplement compared to a healthy diet on body composition, lipids, glucose, insulin and other metabolic syndrome risk factors in overweight and obese individuals. *Br J Nutr.* 2011;105:90-100.

Papathanasopoulos A, Camilleri M. Dietary fiber supplements: effects in obesity and metabolic syndrome and relationship to gastrointestinal functions. *Gastroenterology.* 2010;138:65-72.

Park Y, Subar AF, Hollenbeck A, Schatzkin A. Dietary fiber intake and mortality in the NIH-AARP diet and health study. *Arch Intern Med.* 2011;171:1061-8.

Post RE, Mainous AG 3rd, King DE, Simpson KN. Dietary fiber for the treatment of type 2 diabetes mellitus: a meta-analysis. *J Am Board Fam Med.* 2012;25:16-23.

Raninen K, Lappi J, Mykkanen H, Poutanen K. Dietary fiber type reflects physiological functionality: comparison of grain fiber, inulin, and polydextrose. *Nutr Rev.* 2011;69:9-21.

Roberfroid M, Gibson GR, Hoyles L, et al. Prebiotic effects: metabolic and health benefits. *Br J Nutr.* 2010;104 Suppl 2:S1-63.

Rock CL. Primary dietary prevention: is the fiber story over? *Recent Results Cancer Res.* 2007;174:171-7.

Ros E, Tapsell LC, Sabaté J. Nuts and berries for heart health. *Curr Atheroscler Rep.* 2010;12:397-406.

Sánchez D, Miguel M, Aleixandre A. Dietary fiber, gut peptides, and adipocytokines. *J Med Food.* 2012;5:223-30.

Sartore G, Reitano R, Barison A, et al. The effects of psyllium on lipoproteins in type II diabetic patients. *Eur J Clin Nutr.* 2009;63:1269-71.

References

Schmitt R, Kleibel F. [Modern therapy of constipation with cellulose derivatives.] *Arztl Wochensch.* 1952;7:1133-5. Undetermined Language.

Slavin J. Fiber and prebiotics: mechanisms and health benefits. *Nutrients.* 2013;5:1417-35.

Slavin JL, Savarino V, Paredes-Diaz A, Fotopoulos G. A review of the role of soluble fiber in health with specific reference to wheat dextrin. *J Int Med Res.* 2009;37:1-17.

Tabbers MM, Boluyt N, Berger MY, Benninga MA. Nonpharmacologic treatments for childhood constipation: systematic review. *Pediatrics.* 2011;128:753-61.

Threapleton DE, Greenwood DC, Burley VJ, et al. Dietary fibre and cardiovascular disease mortality in the UK Women's Cohort Study. *Eur J Epidemiol.* 2013;28:335-46.

Threapleton DE, Greenwood DC, Evans CE, et al. Dietary fibre intake and risk of cardiovascular disease: systematic review and meta-analysis. *BMJ.* 2013a;347:f6879.

Threapleton DE, Greenwood DC, Evans CE, et al. Dietary fiber intake and risk of first stroke: a systematic review and meta-analysis. *Stroke.* 2013b;44:1360-8.

Topping DL, Clifton PM. Short-chain fatty acids and human colonic function: roles of resistant starch and nonstarch polysaccharides. *Physiol Rev.* 2001;81:1031-64.

US Department of Agriculture (USDA) and Department of Health and Human Services (HHS). 2010 Dietary Guidelines for Americans. Available at: http://www.dietaryguidelines.gov. Accessed January 30, 2014.

USDA, Agricultural Research Service. What We Eat in America: nutrient intakes from food by gender and age. National Health and Nutrition Examination Survey (NHANES) 2009–2010 [cited 2013 Dec 13]. Available from: http://www.ars.usda.gov/SP2UserFiles/Place/12355000/pdf/0910/Table_1_NIN_GEN_09.pdf.

US Food and Drug Administration (FDA). Health Claims Meeting Significant Scientific Agreement (SSA). Last updated January 28, 2014. Available at: http://www.fda.gov/Food/IngredientsPackagingLabeling/LabelingNutrition/ucm2006876.htm. Accessed January 30, 2014.

UK Food Standards Agency (FSA). FSA Nutrient and Food Based Guidelines for UK Institutions. 2006. Available at: http://multimedia.food.gov.uk/multimedia/pdfs/nutguideuk.pdf. Accessed January 30, 2014.

UK FSA. McCance and Widdowson's The Composition of Foods, Sixth summary edition. Royal Society Chemistry, Cambridge: 2002.

References

Vignec AJ, Mitty VC. Treatment of chronic constipation in childhood. *J Pediatr.* 1952;40:576-8.

Vuksan V, Jenkins AL, Jenkins DJ, et al. Using cereal to increase dietary fiber intake to the recommended level and the effect of fiber on bowel function in healthy persons consuming North American diets. *Am J Clin Nutr.* 2008;88:1256-62.

Vuksan V, Jenkins AL, Rogovik AL, et al. Viscosity rather than quantity of dietary fibre predicts cholesterol-lowering effect in healthy individuals. *Br J Nutr*. 2011;106:1349-52.

Watzl B, Girrbach S, Roller M. Inulin, oligofructose and immunomodulation. *Br J Nutr.* 2005;93 Suppl 1:S49-55.

Weickert MO, Arafat AM, Blaut M, et al. Changes in dominant groups of the gut microbiota do not explain cereal-fiber induced improvement of whole-body insulin sensitivity. *Nutr Metab.* 2012;8:90.

Wells HF, Buzby JC. Dietary Assessment of Major Trends in U.S. Food Consumption, 1970-2005. Economic Information Bulletin 33. USDA, Economic Research Service, Washington: 2008. Available at: www.ers.usda.gov/publications/eib33/eib33.pdf. Accessed February 27, 2012.

Willis HJ, Slavin JL. "Dietary Fiber" in Modern Nutrition in Health and Disease, 11th ed. Ross AC, Caballero B, Cousins RJ, Rucker KL, Ziegler TR (ed). Lippincott Williams & Wilkins, Baltimore: 2012.

Willis HJ, Eldridge AL, Beiseigel J, Thomas W, Slavin JL: Greater satiety response with resistant starch and corn bran in human subjects. *Nutr Res.* 2009;29:100-5.

Wolever TMS, Jenkins DJA. "Effect of dietary fiber and foods on carbohydrate metabolism" in CRC Handbook of Dietary Fiber in Human Nutrition, 2nd ed. Spiller GA (ed). CRC Press, Boca Raton (FL): 1993.

Wolfram T, Ismail-Beigi F. Efficacy of high -fiber diets in the management of type 2 diabetes mellitus. *Endocr Pract.* 2011;17:132-42.

Wood PJ, Anderson JW, Braaten JT, et al. Physiological effects of beta-D-glucan rich fractions from oats. *Cereal Foods World.* 1989;34:878-82.

World Cancer Research Fund (WCRF) and American Institute for Cancer Research (AICR). Food, nutrition, physical activity, and the prevention of cancer: a global perspective. WCRF/AICR, Washington, DC: 2007.

Ye EQ, Chacko SA, Chou EL, et al. Greater whole-grain intake is associated with lower risk of type 2 diabetes, cardiovascular disease, and weight gain. *J Nutr.* 2012;142:1304-13. Erratum in: *J Nutr.* 2013;143:1524.

Zhang Z, Xu G, Liu D, et al. Dietary fiber consumption and risk of stroke. *Eur J Epidemiol.* 2013;28:119-30.

Zhang Z, Xu G, Ma M, et al. Dietary fiber intake reduces risk for gastric cancer: a meta-analysis. *Gastroenterology.* 2013;145:113-120.