FOOD SCIENTIST'S GUIDE TO DIETARY FIBER

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Abstract

In the past 50 years or so dietary fiber has become an increasingly significant area of nutritional focus, debate, and research. Advances in food production practices have resulted in more and more refined foods being available and consumed throughout the world and particularly in developed nations such as the United States. While refined foods are typically more palatable to consumers, the content of dietary fiber is greatly reduced. Currently many diseases are believed to be associated with a lack of dietary fiber intake, and furthermore significant health benefits are thought possible via increased consumption of many dietary fibers. These issues are discussed in Chapter 2- Dietary Fiber and Disease.

There is not a well accepted definition for dietary fiber, but most reference the human inability to fully digest fibers, fibers being made up of various monomer units of variable length, and some mention plant origin. In many ways the definition of dietary fiber is connected to the analytical methods used to quantify it, which there are many, several of which are detailed in Chapter 5- Analytical Techniques for Dietary Fiber. Newer ingredients that are not quantified by typical fiber analysis methods have created the need for additional assays.

Dietary fiber is subject to all sorts of labeling regulations and a few nutritional claims. This has resulted in many manufacturers taking an interest in increasing the fiber content of their products while maintaining product quality and label friendliness. There are many raw materials/ingredients that can increase the fiber content in foods, each with its own set of functional and sensory characteristics. These are detailed in Chapter 7 and include acacia gum, beta glucan, cellulose, chitin/chitosan, corn bran, corn fiber, inulin, oat Bran/oat fiber, pea fiber, pectin, polydextrose, psyllium, resistant starch, rice bran, soy fibers, wheat bran, and wheat fiber. These fibers are unique in their functional capability and effect on flavor and texture. Discussion of the product development considerations includes these functional characteristics as well as cost, ingredient labeling requirements, usage levels, other sensory characteristics, storage stability, and effect on water activity.

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I would like to thank Dr. J. Scott Smith for his guidance and assistance throughout my time at Kansas State University and particularly in the completion of this report. He was essential in helping me keep my work progressing and helping me work through some of the many issues that came up along the way. I would also like to thank Kelly Getty and Fadi Aramouni for their involvement in my graduate committee. I greatly appreciate all their questions and feedback.

Dedication

This paper is dedicated to the many, many people who have been involved in my education throughout my life. The list is long and includes many influential professors, industry professionals, academic and industry colleagues, and most importantly my family. I have been and continue to be inspired in my academic discipline by those that I work with, but my foundational determination to advance my knowledge and my career began with my mother and father. Very early in my life they taught me about the various paths one could follow, certainly while emphasizing that using education as a springboard to success was a good idea. I will always remember conversations with my grandmother (God rest her soul) that centered around her thinking I was crazy spending so much time on my school work, often late into the night with ample supplies of Mountain Dew or other caffeinated beverages. Yet she and others offered their continual support of my effort and congratulations at the many milestones along the way.

At this stage of my life, now a husband and father myself, I dedicate this paper to my wife, Melissa, and son, Conner. I believe that the many late nights and time away from them will benefit us all in the long run. They continue to inspire me to be my best, for me and for them, and provide me with a welcoming family that helps take my mind off of life's many difficulties. Thankfully, smiles and excitement from Conner are enough to erase all of the day's troubles, if just for a while.

So to all of those who have encouraged and supported me through this crazy journey, I thank you!

-Jon Fisher

Preface

This paper is intended to provide an encompassing overview of the world of dietary fiber from the point of view of a Food Scientist. Therefore, a wide variety of topics will be covered, from a historical perspective of the role of dietary fiber, health implications, functional benefits in the body, methods of analysis, and all the way to exact chemical structures and processes for manufacture of specific dietary fibers.

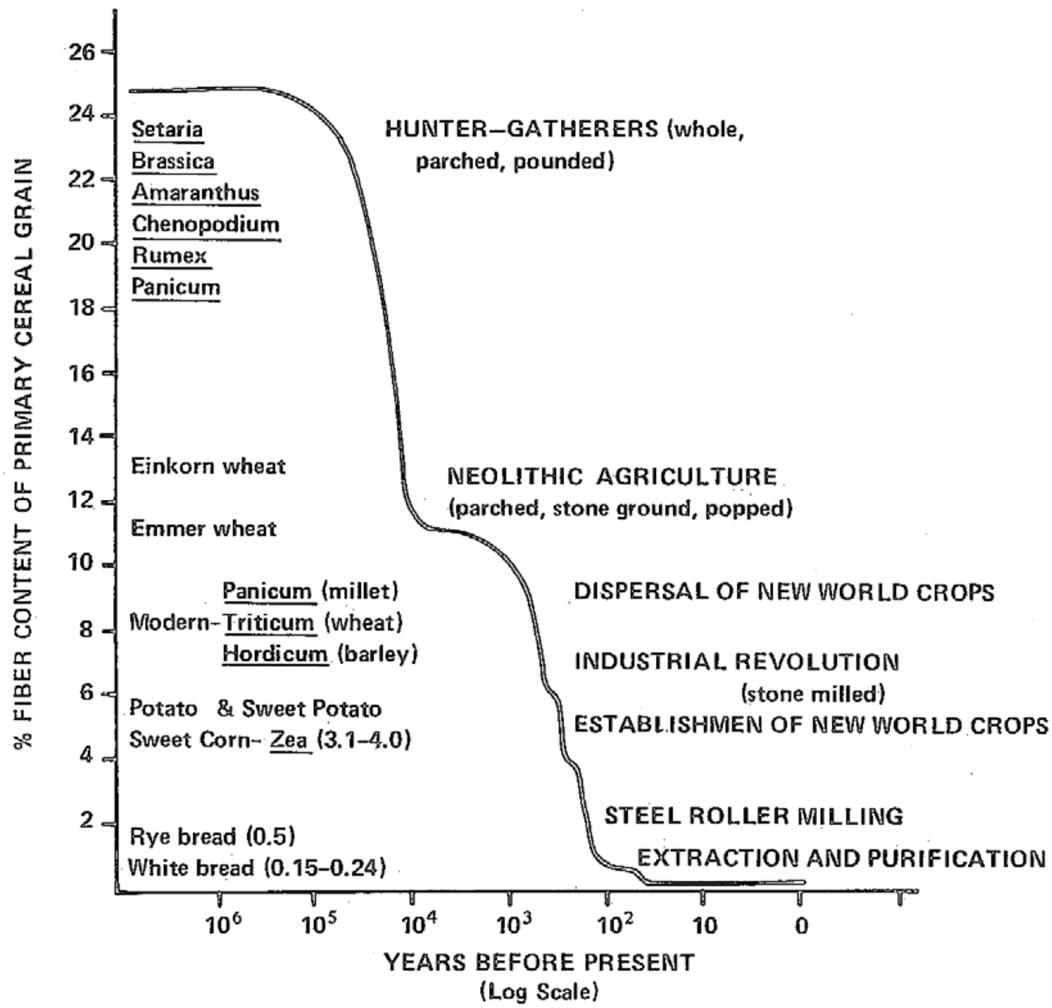
By no means does this paper fully cover all of the complex issues in the realm of dietary fiber. Many issues are still being debated in the scientific community and the need for research in various areas is significant. Understand that new research is being completed all the time and the world of dietary fiber continues to change. The intention of this paper is to give a bit of information on many of the issues present today, but full understanding will often require further research into each issue of interest.

With these things in mind, I hope you find this paper to be a useful resource. The wide variety of compounds that act as dietary fiber makes studying them very challenging, yet interesting, and certainly controversial. Without question, the information in this paper is challenged all the time by various scientists and researchers. It seems that dietary fiber is in somewhat of a discovery and exploration phase at this time, but in the near future greater consensus will reached and some of the controversy will be laid to rest.

CHAPTER 1 - Historical Perspective on Dietary Fiber

Dietary fiber has been a part of human nutrition since the beginning of time. In fact, it used to be a more significant part of the human diet, but the advancement of societies has resulted in more and more refinement of the foods we eat and thus a reduction in the amount of dietary fiber many foods contain. Figure 1.1 from Spiller (1993) shows this major reduction in dietary fiber consumption based on the reduction in fiber content of primary cereal grains.

Figure 1.1 Reduction in Fiber Content of Cereal Grains- Hunter-Gatherers to Today (Spiller, 1993)



According to Spiller (1993), the diet of the hunter-gatherer of 20,000 years ago was based on unrefined greens, seeds, stalks, roots and other plant materials with limited animal products. When comparing that with the diet of most Americans today, there is a huge disparity in fiber consumption. The typical diet of many Americans contains a great proportion of animal products, mostly refined plant materials, and a minor portion of unrefined fruits and vegetables. The difference in fiber content of these two diets is very significant.

The beneficial effects of dietary fiber in combating constipation have shown up in recorded history several times. The belief that course foods of plant origin relieved constipation can be tracked all the way back to the 4^{th} century B.C., and historians cite a few more times between this time and the 19^{th} century where this effect was noted (Spiller, 1993). The 20^{th} century brought more interest in dietary fiber and whole grains, although it was not the subject of major research studies and greater nutritional focus until the 1960's, when it began to gain a position of greater importance in the minds of researchers and health professionals. Since this time, countless publications have reported the beneficial effects of fiber and the potential impact on all sorts of conditions and diseases, as is discussed in Chapter 4 - Dietary Fiber and Disease.

CHAPTER 2 - Definition of Dietary and Functional Fiber

The definition of dietary fiber varies significantly depending on the source. Spiller (1993) offers the following five definitions of dietary fiber:

- Plant substances not digested by human digestive enzymes, including plant cell wall substances (cellulose, hemicelluloses, pectin, and lignin) as well as intracellular polysaccharides such as gums and mucilages. Largely identical to undigested carbohydrates and lignin.
- The remnants of plant cells resistant to hydrolysis by the alimentary enzymes of man.
- The sum of lignin and the polysaccharides that are not hydrolyzed by the endogenous secretions of the human digestive tract.
- The sum of plant nonstarch polysaccharides and lignin.
- The remnant of plant foods resistant to hydrolysis by the alimentary enzymes of humans.

There are a variety of other definitions of dietary fiber found in the literature:

- The sum of nondigested components of a foodstuff or food product (BeMiller, 2003).
- Substances in food (essentially from plants) that are not digested by the processes that take place in the stomach or small intestine (Wardlaw, 1999).
- 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 (Stauffer, 2006).

Notice the wide variety of language used. Some definitions reference plants, indirectly stating that non-plant sources should not qualify as dietary fiber. Some of these definitions include resistant starch as dietary fiber, some do not. All of the definitions reference the inability of human enzymes and processes to degrade and utilize these molecules. Much controversy exists about the definition of dietary fiber and this is a debate that continues with the advent of new materials that could potentially act as or be analyzed as dietary fiber. Stauffer (2006) offers the following explanation about all the confusion surrounding the definition of dietary fiber:

> "In dietary fiber definitions state: insoluble dietary fiber is the insoluble residue after enzymatic digestion, soluble dietary fiber is the digested material that precipitates in 78% ethanol, total dietary fiber is the sum of soluble and insoluble dietary fiber, physiological dietary fiber is soluble at 78% ethanol but provides beneficial effects, and some "fiber" doesn't fall neatly into any of these categories."

From the viewpoint of physiologists and nutritionists, the definition should only include substances which produce the desired effects of dietary fiber in the body. Establishing this cause and effect relationship can sometimes prove difficult. This adds to the confusion and controversy over what constitutes dietary fiber and what exactly is reported by the analytical procedures used to quantify it.

The controversy surrounding the definition of dietary fiber has lead to a relatively new concept gaining approval of many scientists- functional fiber. Stauffer (2006) refers to this as physiological dietary fiber and defines it as soluble in 78% ethanol but providing beneficial effects in the body. NAS (2005) defines functional fiber as isolated, nondigestible carbohydrates that have beneficial physiological effects in humans. Generally, functional fiber refers to the wide body of compounds that act as dietary fiber in the body but are not quantified in traditional dietary fiber analysis methods. They may or may not be of plant origin. Examples of these types of fiber include inulin and polydextrose. There are many of these fibers being used today and more being developed and commercialized all the time.

CHAPTER 3 - Molecular Aspects of Dietary Fiber- Nomenclature, Composition, and Bonding

Many of the molecules classified as dietary fiber are derived from plant cell walls and provide structure and rigidity to the plant. Dietary fiber is classified as soluble or insoluble in water. Generally, the following groups of compounds are considered dietary fiber: pectins, hemicelluloses, cellulose, lignin, hydrocolloids, and mucilages. Refer to table 1.

Table 1 Dietary Fiber Components in Foods (Spiller, 1993)

Dietary Fiber Components of Foods			
Classical nomenclature	Solubility Characteristics	Classes of polysaccharide	Nomenclature in dietary fiber literature
Plant Cell Wall Components			
Pectic substances	Water Soluble[a]	Galacturonans Arabinogalactans β-glucans Arabinoxylans	Noncellulosic polysaccharides Nonstarch polysaccharides Dietary Fiber
Hemicelluloses	Insoluble in Water Soluble in alkali	Arabinoxylans Galactomannans Xyloglucans	
α-Cellulose	Insoluble in alkali	Cellulose (glucan)	Cellulose Nonstarch polysaccharides Dietary Fiber
Lignin	Insoluble in 12M H_2SO_4	Lignin[b] (Klason) Noncarbohydrate	Lignin Dietary Fiber
Nonstructural Components			
Gums Mucilages	Water soluble or Dispersable[c]	Galactomannans Arabinogalactans Wide range of branched and substituted galactans	Noncellulosic polysaccharides Nonstarch polysaccharides Dietary Fiber

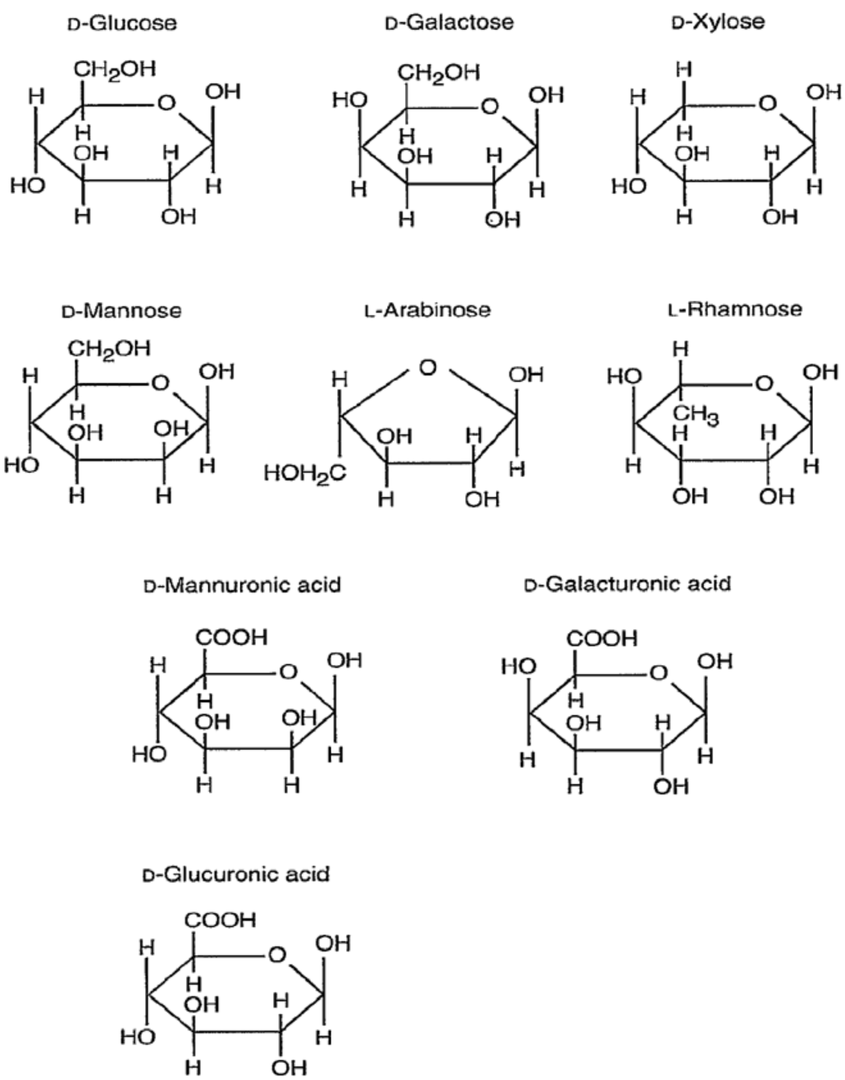
[a] Solubility depends on pH; in many fractionation schemes chelating agents such as EDTA or ammonium oxylate are used.
[b] Lignin is the name given to a group of complex polymers of phenylpropane.
[c] Hot water is usually necessary and colloidal viscous solutions are produced.

Depending on what definition of dietary fiber is ultimately accepted by the scientific community, resistant starch could be added to this list of compounds.

Structural Units of Dietary Fiber

The chemical and molecular structure of dietary fibers is typically similar to that of polysaccharides, although many exceptions exist. The number of monomer units in the chains vary, but many are classified as poly (greater than 10 units), some as oligo (2-10 units). Among the compounds that are generally accepted as dietary fiber, there are some structural units commonly found. Nelson (2001) characterizes these structural units in Figure 3.1.

Figure 3.1 Typical Monosaccharides and Uronic Acids in Fiber (Nelson, 2001)



Soluble Fiber

Soluble fiber is water soluble dietary fiber that produces viscosity in solution (Duyff, 1996). The term soluble describes the state of the fiber during the analytical process; soluble fiber is soluble until the precipitation step where it is subjected to 78% ethanol. This portion of dietary fiber is made up of hydrocolloids, mucilages, and pectin. Soluble fiber is known to help lower cholesterol and help regulate glycemic response. Soluble fiber can be fermented by bacteria in your large intestine, sometimes producing significant gas (NAS, 2005). This is dependent on the fiber source and can be reduced somewhat by moderately increasing your fiber uptake over several months.

Insoluble Fiber

Insoluble fiber is not soluble in water and is made up of cellulose, hemicellulose, and lignin. In analytical methods, this fiber is essentially isolated by filtration. This fiber is responsible for much of the structural integrity of plants (Duyff, 1996). Insoluble fibers help decrease transit time by holding onto water and adding bulk to the stool. This promotes colon health and decreases the resonance time for hazardous substances. Insoluble fibers are fermented in the intestine to a lesser extent than soluble fibers (Anderson et al., 2009).

Crude Fiber

Crude fiber, somewhat of an outdated term, is not well linked to the current definition(s) of dietary fiber. Spiller (1993) defines crude fiber as the remnants of plant material after extraction with acid and alkali. It is based on an outdated method of analysis which poorly characterized the fiber content of foods as defined in the current timeframe. The method for determining crude fiber involves a finely ground, air dried, food sample. The fat is extracted and then the sample undergoes boiling in acid and alkali, then is dried and weighed. This weight is subtracted from the post ashing weight to produce the amount of crude fiber (BeMiller, 2003). This method measures variable amounts of cellulose and lignin but completely misses any hydrocolloids, hemicelluloses, and pectin (BeMiller, 2003). Essentially this method was used in the absence of more accurate methods used today and should not be used for food analysis in modern times.

Functional Fiber

Functional fiber can reference two things depending on your frame of reference and thus creates some confusion. Functional fiber can mean the fiber that works as a functional ingredient within a food system. This could be the use of gums to thicken a product matrix. The other meaning of functional fiber, and the one more applicable to this paper, is: isolated, nondigestible carbohydrates that have beneficial benefits in humans (NAS, 2005). This refers to fibers that are isolated from their source material and the link between the desired health affect is directly correlated to the consumption of that fiber in organized research studies.

Lignin

Lignin is not a polysaccharide but rather a polyphenylpropane polymer. It is an insoluble polymer made up of cinnamyl, syringyl, and guaicyl units and has known structural properties (Nelson, 2001). Lignin is most often a small amount of the overall dietary fiber present in any particular food product. Nelson (2001) states that lignin is not isolated and sold for use in food products. One could argue that the low content in most sources and the physical properties of this polymer do not lend itself to quality use in food products, or at least not at the levels required to achieve health claims or other functional benefits.

Pectins

Pectins are made up of linear chains of D-galacturonic acid units with occasional rhamnose units dispersed in the chain and are typically soluble (thus are soluble fiber), although substitutions on the linear chain impact the solubility. The linear chain can have various side chains of galactose, glucose, rhamnose, or arabinose in place of the typical acid or methyl ester groups that are commonly found on the galactose units (NAS, 2005; Nelson, 2001). Pectins account for the largest contribution to soluble fiber from plant materials (Nelson, 2001). Pectins are produced commercially and often used for their gelling properties in jams and other products. Upon processing, pectins can be divided into high and low methoxylated groups. High methoxylated pectins are used in jams with high sugar content, while low methoxylated pectins are used in low sugar and low calorie products as they do not require the high sugar concentration to make a gel (NAS, 2005).

Resistant Starch

Resistant starch is an indigestible form of starch found in some legumes, green bananas, and some processed carbohydrate-rich foods (e.g. potatoes) (Stauffer, 2006). Resistant starches occur naturally in some foods and can also be formed during cooking or processing steps (NAS, 2005). It is a class of starches that are not easily broken down by the digestive process. These starches are resistant to amylase in the small intestine (Nelson, 2001). According to Leszczyński (2004), resistant starch is the sum of starch and products of its degredation not absorbed in the small intestine of a healthy human. This starch moves into the large intestine and is fermented by the microflora there. There are four types of resistant starch as shown in Table 2.

Table 2 Types of Resistant Starch (Nelson, 2001)

Types of Resistant Starch		Occurrence
RS1	Physically inaccessible starch	Partially milled grains, seeds, and legumes
RS2	Granular starch	Banana starch, native potato starch
RS3	Nongranular, retrograded, or crystalline starch	Ready-to-eat breakfast cereals, cooked and cooled potato
RS4	Chemically cross-linked starch	Produced through chemically cross-linking starch

As explained by Nelson (2001), the four starch types are referred to as RS1 through RS4. RS1 are starch molecules that are physically unavailable to the digestive system due to encapsulation in plant material such as a seed. RS2 are starch molecules that remain in their granular form in the final food product (uncooked peas and potatoes are examples). RS3 is retrograded starch which is less available to enzymes due to its gelatinous network. RS4 are starch molecules that have been chemically cross linked via ester, ether or other linkage and thus impact the ability of amylase to breakdown the molecule (Nelson, 2001; NAS, 2005). For more information, refer to the resistant starch section in Chapter 7.

Glycosidic Bond Linkages/Cellulose/Beta Linkage

Dietary fiber is a unique and diverse group of molecules. Table 1 shows the wide variety of compounds that are considered dietary fiber. The key is each of these compounds resists human metabolic processes- the acidic conditions of the stomach, the enzymes present throughout the gastrointestinal tract, and the various other pathways for degrading food for energy and essential nutrition. In the case of cellulose, beta-glucosidic linkages are the reason for human's inability to digest the molecule. Beta linkages are the connecting points of various saccharide units that form the polysaccharide. Most biological materials of this nature (such as starch) contain the alpha linkages, some with a few beta linkages. Take the example of cellulose and starch. Cellulose is 100% dietary fiber, is made up of all beta linked glucose, and is a structural molecule for plants. Starch is alpha linked glucose (containing both 1→4 and 1→6 linkages) and is the major energy storage system of plants. Refer to Figures 3.2 and 3.3 to see structural diagrams of cellulose and starch (amylose).

In very specific terms, the alpha linkage has the bond located above the plain of the chiral carbon at the acetal bond site, where the bond in beta configuration is below the plane. This difference in bond arrangement is the reason that cellulose structures are mostly linear (Ophardt, 2003). Alpha 1→4 starch (known as amylase) exhibits a coil-like structure, something like that of a spring. Starch containing 1→4 and 1→6 alpha linkages (amylopectin) exhibits a branching effect resulting from the 1→6 linkages and therefore has a very different tertiary structure.

Figure 3.2 Structure of Cellulose

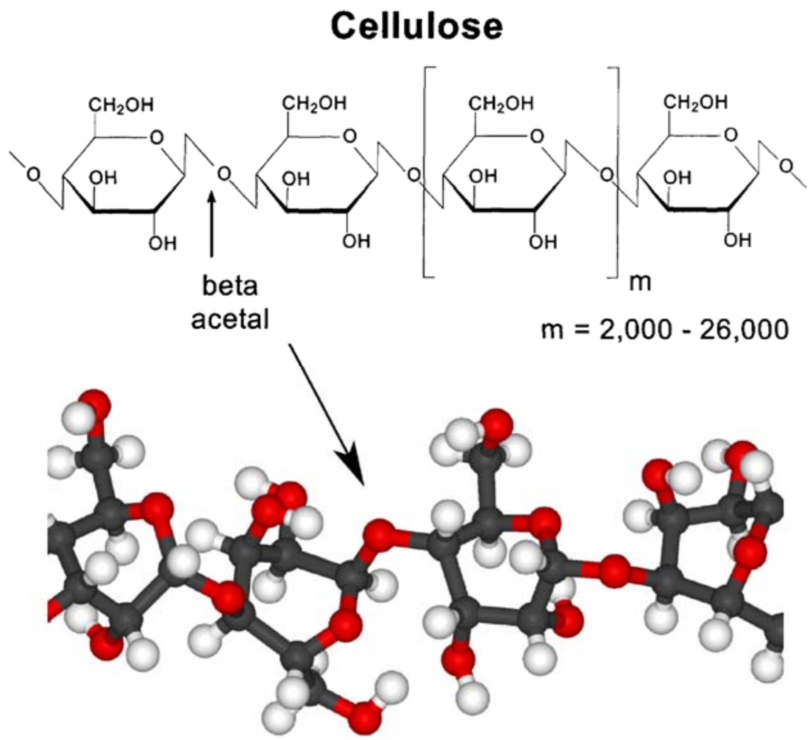
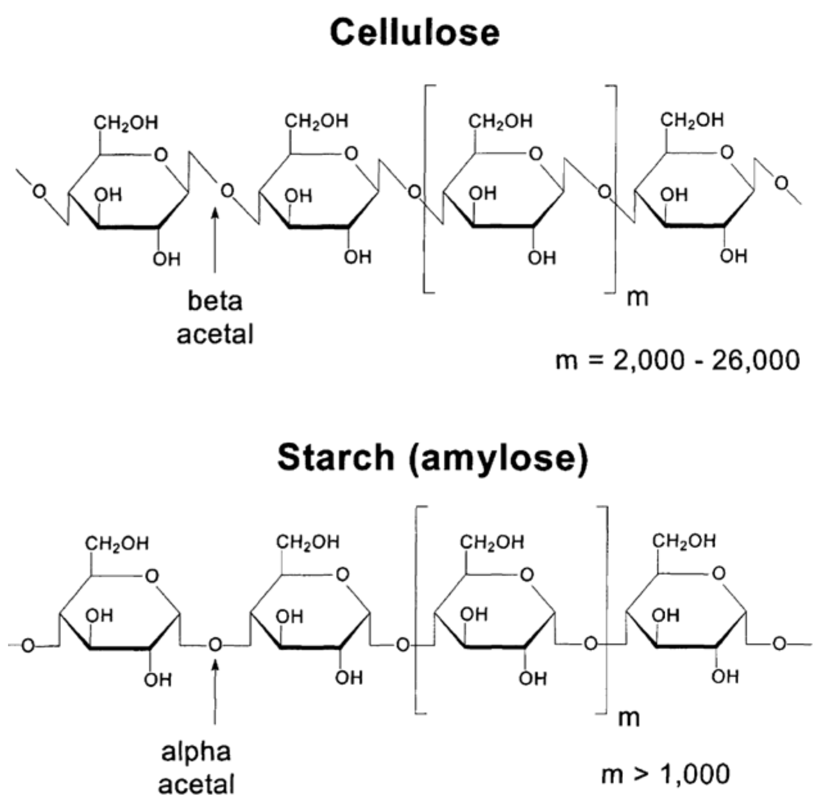


Figure 3.3 Structure of Cellulose vs. Starch



CHAPTER 4 - Dietary Fiber and Disease

Dietary fiber is believed to have many health benefits related to its action in the digestive tract. Many of the conditions listed below lack controlled studies that unequivocally demonstrate the mechanism and effectiveness of dietary fiber, yet there are significant pieces of information that lead researchers to believe in the correlations. Many of the conditions are associated via epidemiological and geographical studies. It should be understood that fiber had not been a highly researched topic until approximately the 1960's, as described in the historical perspectives section of this paper. Increasing interest in fiber will likely result in more studies attempting to identify the exact mechanism of the associations made through the many studies referenced below.

Bowel Disease/Irritable Bowel Syndrome/Colitis/Crohn's Disease

Bowel Disease, Irritable Bowel Syndrome, Colitis, and Crohn's Disease all involve issues with the way in which the small and large intestines process food. Each has its own unique set of symptoms and related issues, but all are believed to be affected, in a positive way, by consuming a diet with adequate dietary fiber. According to Spiller (1993), one study determined patients with Crohn's Disease have been shown to consume only 25% of the fruit and vegetable fiber as those who don't have the disease. However, studies conflict on whether addition of a high fiber diet results in reduced symptoms of the disease. In the case of Irritable Bowel Syndrome, metabolic byproducts of fiber fermentation (short chain fatty acids) may play an important role in treatment of the condition.

Colon Cancer

Dietary fiber was first suspected of being linked to colon cancer through epidemiological studies that suggested Western developed nations had a much greater prevalence of the disease than developing countries (Spiller, 1993). Most of the studies cited by Spiller (1993) have shown an inverse relationship between increasing fiber consumption and increasing disease prevalence. There are several proposed methods of action. The bulking property of dietary fiber is thought to dilute the concentration of toxic substances (Duyff, 1996). The increase in transit time is thought to reduce the time for toxins to act upon the intestines. Other theories suggest that fiber binds carcinogenic bile acids and results in more short chain fatty acid production in the colon and these changes result in some protective effect (Anderson et al., 2009). According to Jones (2007), animal studies consistently link fiber consumption to a reduction of colon cancer risk, but human studies have not consistently yielded the same results.

Constipation

It is well known that dietary fiber helps relieve constipation. In fact, most over the counter medications use psyllium as the active ingredient, refer to chapter 7 for more information on psyllium. Fiber relieves constipation with a similar mechanism to that of Irritable Bowel Syndrome. The increased stool bulk, water holding, and speed of transit are all things that help relieve constipation and each of these has been linked to fiber consumption in a wide variety of research studies (NAS, 2005). Cellulose, inulin, oat fiber, pectin, polydextrose, and psyllium have all been shown to increase fecal bulk in clinical studies (NAS, 2005).

Diabetes

Mendell (1997) states soluble fiber is responsible for the beneficial effect of dietary fiber on diabetes because it slows the uptake of sugars into the bloodstream by slowing gastric emptying and by coating the small intestine. Diabetes prevalence is correlated with fiber intake among various populations and its use in treating the disease is also well studied and documented (Spiller, 1993). The vast majority of epidemiological and intervention studies show that high fiber (even more so high carbohydrate and high fiber) diets help improve glycemic control and reduce the need for insulin in diabetic subjects (NAS, 2005). Many of these studies are highly controlled and thus offer significantly more confidence than many of the available studies on dietary fiber. Increased intake of soluble fiber can lower blood sugar levels in diabetic patients (Duyff, 1996).

Diverticulosis/Diverticulitis

Diverticulosis is a condition involving inflammation and bulging of the diverticuli, pouches in the intestine wall, of the large intestine (Mindell, 1997). Diverticulitis is further complication of an untreated diverticulosis condition. For treatment of these conditions, Mindell (1997) recommends avoiding processed foods and eating a diet rich in fiber. Spiller (1993) suggests that while studies have not yet proven a lack of fiber to be the cause of this condition, geographical studies strongly suggest it to be true. Developed areas such as Europe and the

Americas have a high incidence of the condition, while less developed areas which rely on unrefined cereal diets have a very low incidence rate. Anderson et al. (2009) state that clinical trials in this area are difficult to execute due to the intermittency of the disease, yet limited clinical data suggests that fiber supplementation helps the condition. Interestingly, when experiencing a flare up of diverticulosis, too much fiber can be bad (Duyff, 1996). Small seeds or skins can upset the condition by getting caught in the diverticuli. The anti-inflammatory properties of inulin and related soluble fibers are believed to reduce recurrent issues with this condition, although no clinical trials support this theory yet (Anderson et al., 2009).

Gallstones

Gallstones are hardened deposits of bile (calcium salts and other components) produced by the gallbladder. Bile is produced to aid the emulsification and digestion of fats, but can lead to radiating pain (Mindell, 1997). Mindell says a sure way to reduce the occurance of gallstones and the pain that comes with this issue is to consume fiber, particularly psyllium. Spiller (1993) states that current theories suggest over-nutrition coupled with low fiber intake and high cholesterol to be the root cause of gallstones.

Heart Disease

Dietary fiber reduces the chances of heart disease mainly via reducing blood cholesterol. Soluble fiber helps lower blood cholesterol, lowering your chance of heart disease (Duyff, 1996). Soluble fiber removes cholesterol by binding bile acid by-products made from cholesterol. Anderson et al. (2009) state that diets high in dietary fiber combat major risk factors for heart disease, such as hypertension, diabetes, obesity, and high blood lipids. Based on a wide body of research information, the National Academy of Sciences concluded that dietary fiber significantly reduced the chance of coronary heart disease in all studies that were executed up to its standards (NAS, 2005). Various figures are reported describing the potential reduction in risk based on consuming a high fiber diet compared to a low fiber diet; approximately a 25% reduction in risk is commonly stated (Jones, 2007; Anderson et al., 2009).

High Cholesterol

High cholesterol can be caused by a complex mix of genetic and lifestyle factors and is known to put humans at a greater risk for heart disease. While there are many things one can do to alleviate this problem, adding sources of soluble dietary fiber is one way of helping reduce cholesterol. Soluble fiber removes cholesterol by binding bile acid by-products made from cholesterol (Duyff, 1996). Although limited studies exist, fiber intake is associated with lower levels of high density lipoprotein (HDL) and low density lipoprotein (LDL) in the blood, as well as lower blood pressure (Anderson et al., 2009; NAS, 2005)). In general, cereal fibers and viscous fibers are most effective in combating high cholesterol (NAS, 2005).

Hyperlipidemia

Hyperlipidemia is affected by dietary fiber similarly to high cholesterol. Binding of and reduced production of bile acids is believed to play a significant role (NAS, 2005). Another mechanism put forth by Spiller (1993) is the increased generation of propionate, which has been shown to reduce cholesterol levels and inhibit cholesterol synthesis. These studies do not correlate well with human studies, which could be explained by a variety of competing factors. Reduced insulin response and altered lipid absorption are likely factors in the affect of dietary fiber on hyperlipidemia (Anderson et al., 2009). Viscous fibers are known to increase the fecal output of lipids, likely due to the viscosity impact in the intestine, but this output is not the believed to be a very significant factor in the ability of fiber to reduce hyperlipidemia (NAS, 2005).

Obesity

Obesity is extremely common in the United States, approximately 2/3 of Americans are technically obese. Dietary fiber offers some hope in combating the obesity epidemic. It is hypothesized that the effects of dietary fiber in the gut and intestinal tract slow the absorption of nutritional components of food and give an increased feeling of fullness. Furthermore, many foods that contain high amounts of dietary fiber are also much more nutritious that those that do not. Generally, the more processed the food, the lower the dietary fiber content and, unfortunately, the lower the nutritional value. This translates to increased weight of humans that consume these foods, as studies have shown a correlation between fiber consumption and body mass index (NAS, 2005). Unfortunately, there are many conflicting intervention studies using fiber to positively affect weight loss, suppress appetite, and feel full longer (NAS, 2005).

CHAPTER 5 - Analytical Techniques for Dietary Fiber

There are two general classes of methods used in dietary fiber analysis- gravimetric and chemical. Generally speaking, gravimetric methods facilitate solubilization of the digestible carbohydrates, lipids, and proteins (BeMiller, 2003). Successful solubilization (via chemical or enzyme) allows filtration and weighing of the undigestible portion. Chemical methods use enzymes to digest the carbohydrates and acid hydrolysis to break the fiber components into monosaccharides. In this method, the monosaccharides are measured and reported as dietary fiber.

The analyses of dietary fiber are somewhat reflective of the definition of dietary fiber, or perhaps vise versa. In any case, a strong definition is important to correctly determining the dietary fiber in a sample. For example, resistant starch is not always accounted for in the dietary fiber analysis. Some methods capture and report the resistant starch, some do not. The analytical technique must be tailored to get the exact results required, depending on what types of fiber are believed to be in the product.

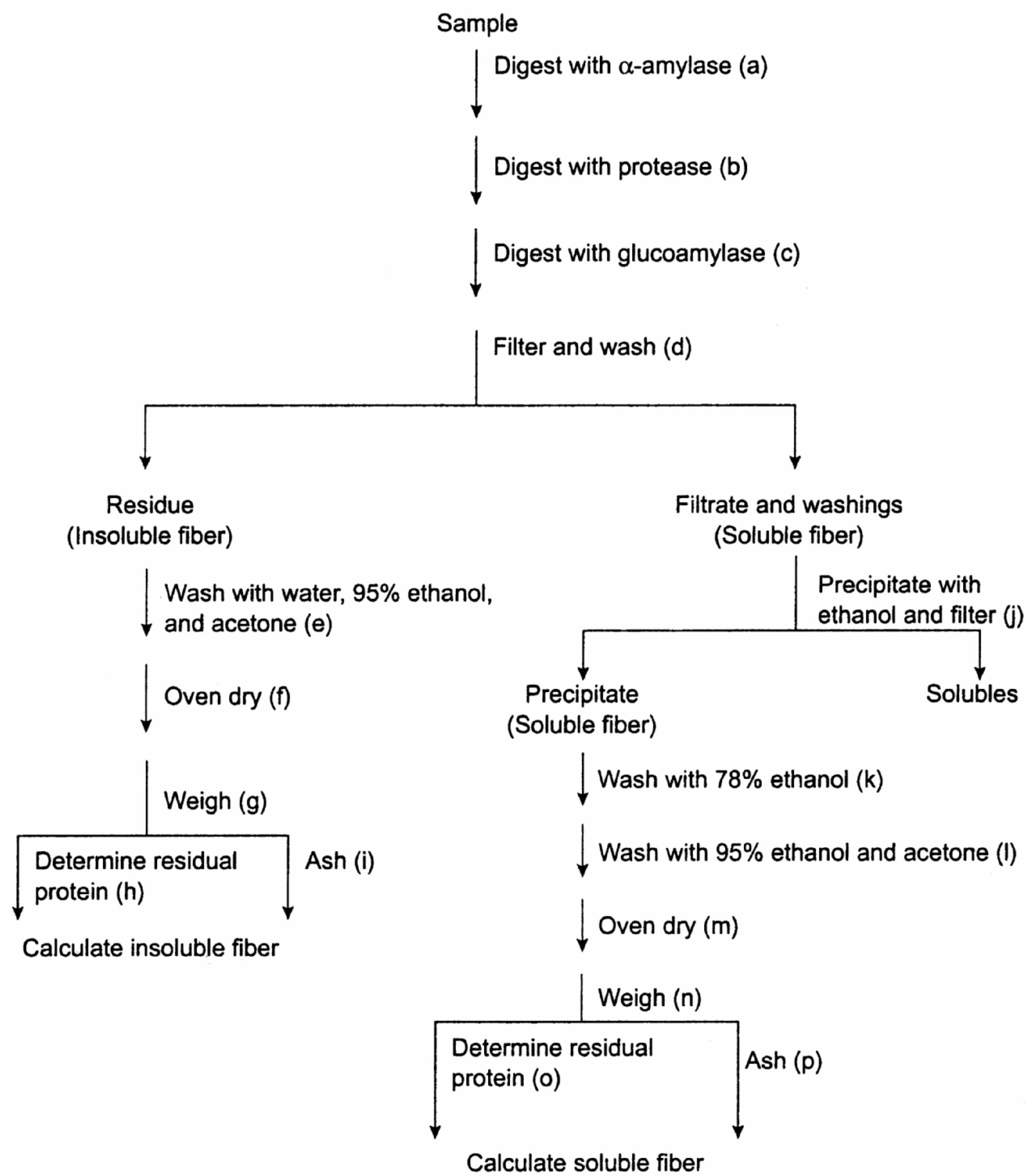
Sample Preparation

The condition of the sample has a significant effect on the ability of the analytical methods to attain clear, consistent, and accurate results. The properties of a good sample for dietary fiber analysis are: low fat, low moisture, finely ground, consistent mix (BeMiller, 2003). A sample high in fat should be put through a lipid extraction. While some liquid products can be analyzed, drying is often necessary.

Gravimetric Methods

The method described here is AOAC method 991.43- Total, Soluble, and Insoluble Dietary Fiber in Foods (AOAC, 2006). Starch and protein are removed via digestion with alpha amylase, protease, and glucoamylase. Filtration isolates the insoluble fiber. Adding ethanol to the filtrate results in the soluble fiber precipitating, allowing it to be filtered. Ethanol and acetone washes are preformed, followed by drying and weighing of the fractions. The soluble and insoluble fractions are analyzed for protein and ash, which are subtracted from the previously determined weight (BeMiller, 2003). Refer to the more detailed Figure 5.1 for a step by step view of the procedure. Note that foods high in simple sugars should undergo extraction with 85% ethanol prior to testing for dietary fiber as the determination could be overstated otherwise.

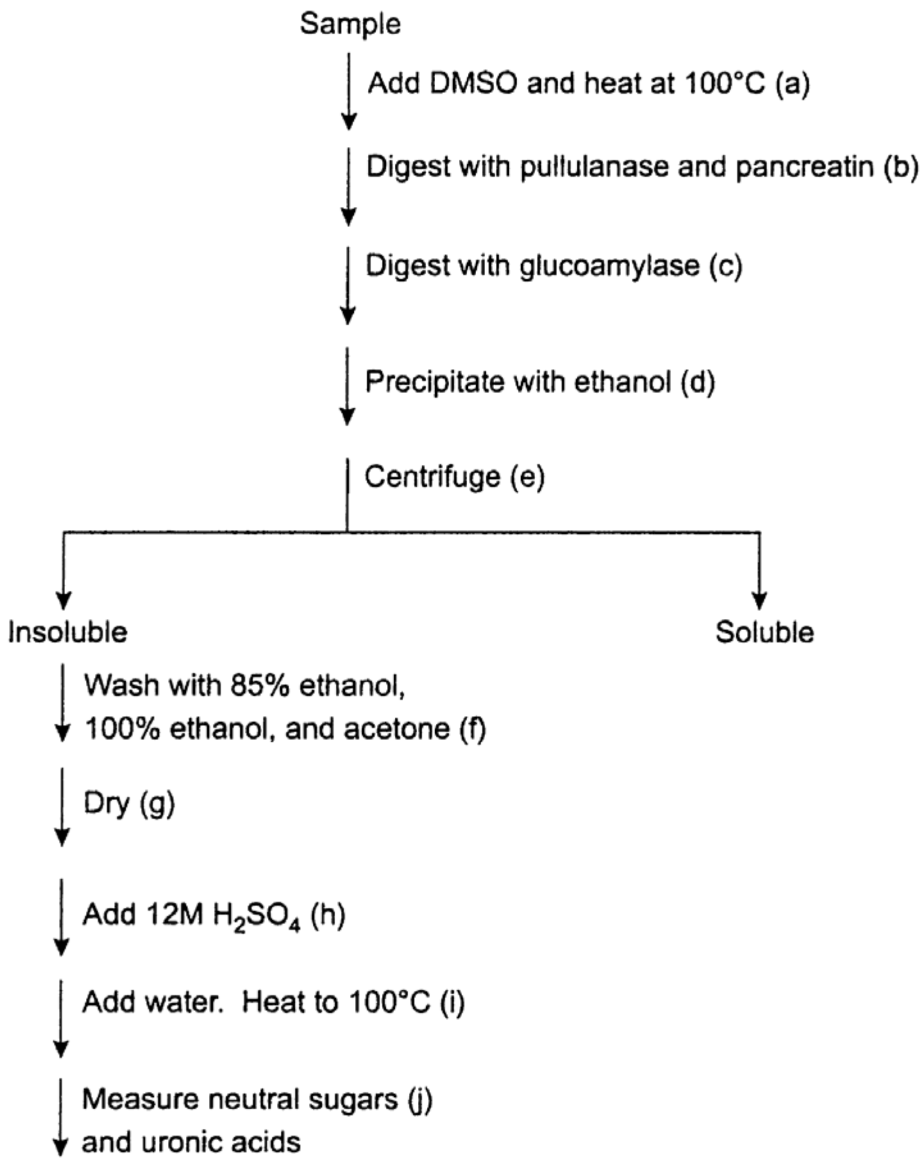
Figure 5.1 Gravimetric Method of Fiber Analysis- (BeMiller, 2003)



Chemical Methods

The Englyst-Cummings procedure is up-to-date and a good alternative to the AOAC method. In this method, shown below in figure 5.2, the starch is gelatinized and digested via enzymatic action (BeMiller, 2003). The soluble fiber is recovered in the filtrate of centrifugation while the insoluble fiber is isolated by the filter. Sulfuric acid hydrolyzes the insoluble fiber and eventually neutral sugars are measured by GC and uronic acids are measured by colorimetry. Not included in this determination of dietary fiber are lignin and resistant starch.

Figure 5.2 Chemical Method of Dietary Fiber Anaylsis (BeMiller, 2003)



Inulin, Resistant Starch, and Other Oligosaccharides Not Determined by Most Analytical Methods

While most legal authorities throughout the world permit inulin and oligofructoses to be classified as dietary fiber, most typical analytical methods do not retain these molecules in the soluble fiber determination because they are soluble in 78% ethanol, which is the analytical step to precipitate them after removing the insoluble fiber. Many substances considered dietary fiber fall in this category, such as inulin, oligosaccharides (raffinose, stachyose, verbacose in legumes), enzymatically hydrolyzed guar gum, cellulose gums, polydextrose, resistant starch, and more (Stauffer, 2006). The role of resistant starch as dietary fiber is debated and thus some methods include it, some ignore it, and some purposefully exclude it.

Many analytical methods have been developed to determine the quantity of these compounds in foods. Many involve the use of amylogulcosidase and inulinase enzymes to chop up the fructose chains which are then quantified by ion exchange chromatography, high performance liquid chromatography (HPLC), or colorimetry.

Resistant starch can be determined in several ways. After total dietary fiber determination via the Prosky procedure (AOAC 991.42), treatment of the sample with dimethyl sulfoxide should solubilize the resistant starch (AOAC, 2006). After drying and re-weighing the sample, the total dietary fiber number is subtracted from the newly obtained number, the resulting difference is assumed to be resistant starch. Another way involves gelatinizing total dietary fiber from the Prosky method, treatment with 2M KOH, and treatment with amyloglucosidase (Stauffer, 2006).

Polydextrose can be determined via AOAC method 2000.11 (AOAC, 2006). Following removal of high molecular weight material, the procedure uses HPLC to separate polydextrose from other compounds and quantified by an electrochemical detector. About 90% of polydextrose is considered to be dietary fiber.

Table 3 illustrates commonly used AACC and AOAC methods used to determine the various components of dietary fiber.

Table 3 Common AACC and AOAC International Methods for Fiber Components in Food (Nelson, 2001)

Method Numbers	Description	Comments
AACC 32-05 AOAC 985.29	Measures total dietary fiber in foods by an enzymatic-gravimetric method	Does not quantitate soluble fibers that are soluble in 78% ethanol (e.g., inulin, polydextrose, fructooligosaccharides, and other oligosaccharides)
AACC 32-21 AOAC 991.42	Measures insoluble dietary fiber in foods by an enzymatic-gravimetric method with a phosphate buffer	Soluble fiber can be determined by utilizing both AOAC 985.29 and AOAC 991.42
AACC 32-21 AOAC 993.19	Measures soluble dietary fiber in foods by an enzymatic-gravimetric method with a phosphate buffer	Total dietary fiber can be determined by utilizing AOAC methods 991.42 and 993.19 together
AACC 32-07 AOAC 991.43	Measures total, soluble, and insoluble dietary fiber in foods by an enzymatic-gravimetric method with a MES-Tris buffer	Does not quantitate soluble fibers that are soluble in 78% ethanol (e.g., inulin, polydextrose, fructooligosaccharides, and other oligosaccharides)
AOAC 2000.11	Measures polydextrose in foods	
AACC 32-32 AOAC 997.08	Measures fructans in foods by ion exchange chromatography	For determination of inulin in foods
AACC 32-22 and 32-23 AOAC 992.28 and 995.16	Measures β-D-glucan component of cereals	

Effect of Processing on Dietary Fiber and Analytical Quantification

Food processing can affect the amount of dietary fiber in a final food product. Enzymes, heat, and acid can attack the fiber molecules and break them down, reducing the total fiber content in the product. Rodriguez et al. (2006) state that the main enzymes collected in fiber fermentation reactions are amylase, proteinase, poligalactuonase, cellulase, and B-galactosidase. Some insoluble fiber is broken down, but the majority of the fermented fiber is soluble. Heating is thought to reduce the hemicelluloses and pectin fractions of dietary fiber the most, yet in the case of wheat bran an increase of dietary fiber has been shown due to heat resistant complexes that are made with protein (Rodriguez et al., 2006). This artificially increases the analytical result.

CHAPTER 6 - Labeling Requirements and Nutritional Claims

Fiber Daily Value

The daily value for dietary fiber is 25g based on a 2000 calorie diet for adults and children age 4 or older (FDA, 2009c).

Fiber Content Claims

Fiber content claims can be made based on Table 4.

Table 4 Fiber Content Claim Levels (FDA, 2009d)

Label Claim	Fiber Requirement
High Fiber	5g or more per serving
Good Source of Fiber	2.5 to 4.9g per serving
More or Added Fiber	At least 2.5g more per serving

Rounding Rules for Total, Soluble, and Insoluble Fiber

The Nutritional Labeling and Education Act (NLEA) sets the rounding rules for the nutrition facts panel on food products. For dietary fiber, the following rules dictate how dietary fiber is labeled (FDA, 2009b):

- Grams of total dietary fiber must be displayed on the nutrition facts panel
    - Less than 0.5g of dietary fiber shall be labeled as 0g
    - Less than 1g but at least 0.5g shall be labeled “Contains less than 1g”
    - 1g or more dietary fiber shall be labeled to the nearest 1g
- Grams of soluble and insoluble dietary fiber are not required on the nutrition facts panel, but are permitted
    - Soluble and insoluble dietary fiber follow the same rounding rules as stated above

Fiber Health Claims

Health claims exist for dietary fiber. They are grouped by claim, food product, and verbiage required for each claim. These are summarized in Table 5.

Table 5 Health Claims Related to Fiber (FDA, 2009a)

Approved Claim	Food Requirements	Claim Requirements	Model Claim Statement
Fiber-containing Grain Products, Fruits, and Vegetables and Cancer 101.76	A grain product, fruit, or vegetable that contains dietary fiber, low fat, and good source of dietary fiber (without fortification)	"Fiber", "Dietary fiber", or "Total Dietary fiber"; "Some types of cancer" or "Some cancers"; Does not specify types of dietary fiber that may be related to the risk of cancer	Low-fat diets rich in fiber containing grain products, fruits, and vegetables may reduce the risk of some cancers, a disease associated with many factors.
Fruits, Vegetables, and Grain Products That Contain Fiber, Particularly Soluble Fiber, and Risk of Coronary Heart Disease 101.77	A fruit, vegetable, or grain product that contains fiber, low saturated fat, low cholesterol, low fat, at least .6 grams of soluble fiber per reference amount (without fortification), and soluble fiber constant provided on label	"Fiber", "Dietary fiber", "Some types of dietary fiber", "Some dietary fibers", or "Some fibers"; "Saturated fat" and "Cholesterol"; "Heart Disease" or "Coronary Heart Disease"; Includes physician statement (individuals with high total or LDL cholesterol should consult their physicians) if claim defines high total or LDL cholesterol	Diets low in saturated fats 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.

Table 6 Health Claims Related to Fiber (cont) (FDA, 2009a)

Approved Claim	Food Requirements	Claim Requirements	Model Claim Statement
Fruits, Vegetables, and Cancer 101.78	A fruit or vegetable, low fat, and good sourcs (without fortification) of at least one of the following: Vitamin A, Vitamin C, or dietary fiber	"Fiber" or "Dietary fiber", or "Total Dietary fiber"; "Total Fat" or "Fat"; "Some types of cancer" or "Some cancers"; characterizes fruits and vegetables as "Foods that are low in fat and may contain Vitamin A, Vitamin C, and dietary fiber"; Characterizes specific food as a "Good source" of one or more of the following: Dietary fiber, Vitamin A, or Vitamin C; Does not specify types of fats or Fatty acids or types of dietary fibers that may be related to risk of cancer.	Low-fat diets rich fruits and vegetables (foods that are low in fat and may contain dietary fiber, vitamin A, or Vitamin C) may reduce the risk of some cancers, a disease associated with many factors. Broccoli is high in vitamins A and C, and is a good source of dietary fiber.

Disqualifying Nutrients

Certain levels of "bad" nutrients disqualify a product from making health claims. This is sometimes referred to as the "jelly bean rule". Products with any of the following characteristics are not considered nutritious enough to allow a health claim. These nutrients are outlined in Table 7.

Table 7 Disqualifying Nutrients for Health Claims (FDA, 2009c)

Disqualifying Nutrient	Foods	Main Dishes	Meal Products
Fat	13g	19.5g	26g
Saturated Fat	4g	6g	5g
Cholesterol	60mg	90mg	120mg
Sodium	480mg	720mg	960mg

CHAPTER 7 - Common Ingredients High in Dietary Fiber-Composition, Functionality, and Manufacturing

The food industry uses many different fiber based ingredients for supplementation of fiber, physical characteristics that they give to the product, or other nutritional benefits they bring to the product. Below are some of the most commonly used ingredients that are high in fiber and pertinent information about them.

Acacia Gum/Gum Arabic

Acacia gum (also known as gum Arabic) is produced from the one of two speicies of tree, the *Acacia senegal* or the *Acacia seyal,* grown in the sub-Saharan region of Africa (Salovarra et al., 2007). This gum is a large and very complex polysaccharide consisting mainly of arabinogalactans and arabinogalactan proteins, resulting in huge molecules of soluble fiber, molecular weight from 300 to 800 kDa. Refer to Figure 7.1 for the structure of Acacia gum.

Figure 7.1 Structure of Acacia Gum (Salovarra et al., 2007)

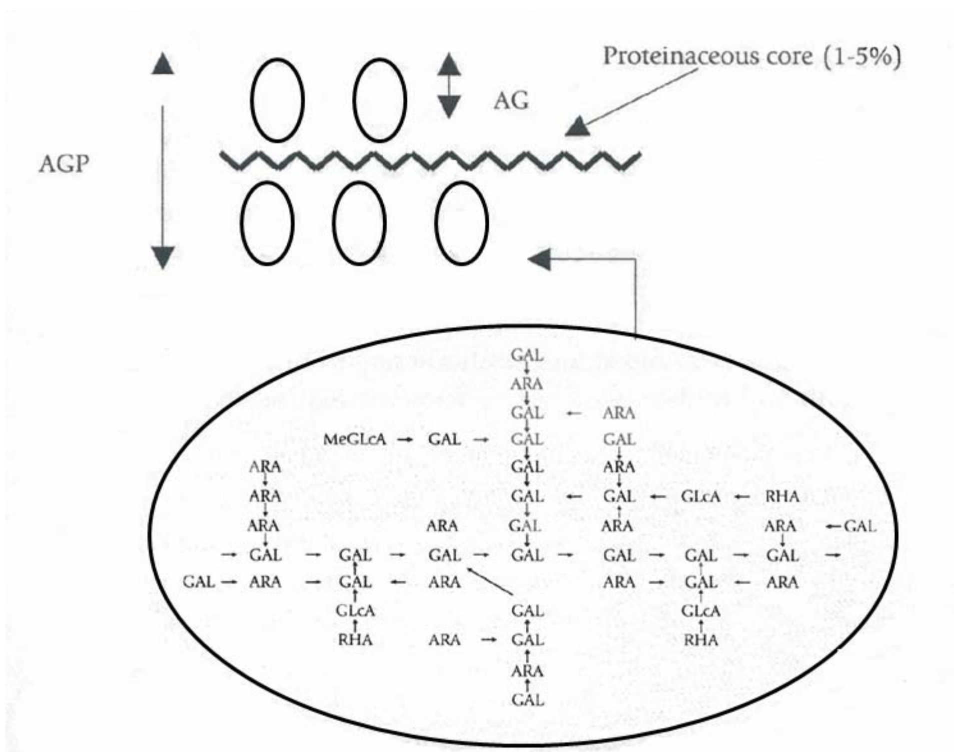
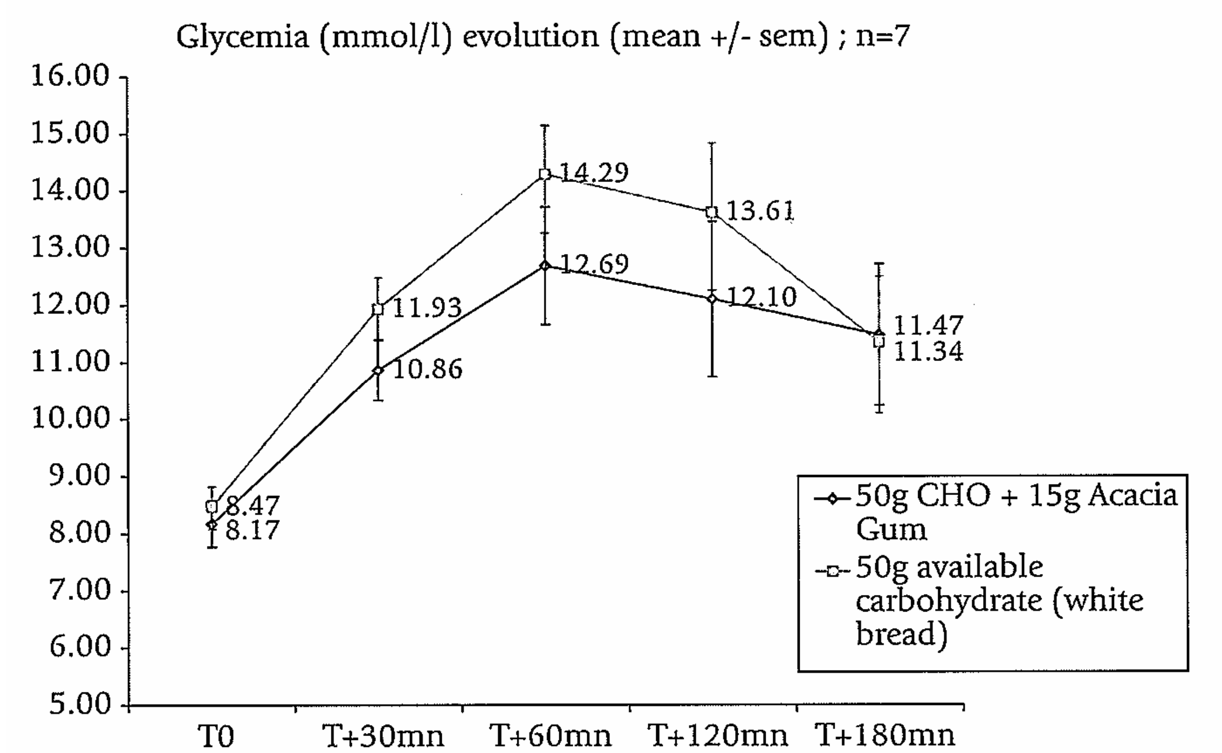


Figure 7.1 shows the arabinogalactan protein chain going vertically along the left side, connected to various proteinaceous branches, upon which large structures of arabinose, galactose, and rhamnose are connected. This large molecular structure results in the functionality it has in solution.

The next figure is a graph of the postprandial glycemic response (average response of the 7 people) after consuming 50 grams of white bread or the bread with 15 grams of Acacia gum. The graph shows the apparent reduction in glycemic response due to the 15g of Acacia gum, although there is some overlap of the confidence interval bars.

Figure 7.2 Glycemia Value vs Time With and Without Added Acacia gum (Salovarra et al., 2007)



It is assumed that the cause of this moderation in glycemic response is due to the soluble Acacia gum thickening the food matrix in the stomach and intestine thus reducing the ability of the digestive system to act upon the food. Salovarra et al. (2007) describe Acacia gum as having very little ability to increase the viscosity of the food matrix, even at high usage levels, perhaps eluding that there may be some other factors at work here.

In addition to moderating glycemic response, Acacia gum is believed to have some significant health benefits. Among these are probiotic effects leading to greater gut health and comfort, reduction of diarrhea, and cardiovascular health (Salovarra et al., 2007).

Beta Glucan

Beta glucans are linear polysaccharides made up of D-glucopyranosyl units connected mostly by (1→4) beta linkages with occasional (1→3) beta linkages (Lazaridou and Biliaderis, 2007). Often there are three or four (1→4) linkages between each (1→3) linkage. This variation in linkages causes differences in the physical and functional properties of these molecules. Cereal beta glucans function as soluble and insoluble fiber, as they are only partially soluble in water (Lazaridou and Biliaderis, 2007).

Beta glucan is a component of cell walls in fungi, algae, oats, barley, rye, and wheat (NAS, 2005; Lazaridou and Biliaderis, 2007). The location of beta glucan within the cereal grain varies- in some cases it is found throughout the grain, in others it concentrates in a particular area. For example, in wheat the majority is found within the bran portion of the grain (Lazaridou and Biliaderis, 2007). When further fractionating wheat bran, beta glucans are found in greater concentrations in the aleurone fraction of wheat bran than in the pericarp fraction (refer to wheat bran for more information on these fractions) (Harris et al., 2005). Because of this variability, processing techniques can greatly alter the beta glucan content of various cereal products.

Beta glucans are associated with reducing blood cholesterol and regulating blood glucose levels (functions associated with soluble fiber). NAS (2005) states that beta glucans minimally increase fecal bulk and thus lack the ability to relieve constipation, somewhat contradicting the concept that they function as both soluble and insoluble fiber. This likely has something to do with the beta glucan source and associated processing, as described above.

The ability to add fiber, provide thickening/gelling, and allow the use of health claims makes beta glucan an interesting option for use in the food industry.

Cellulose

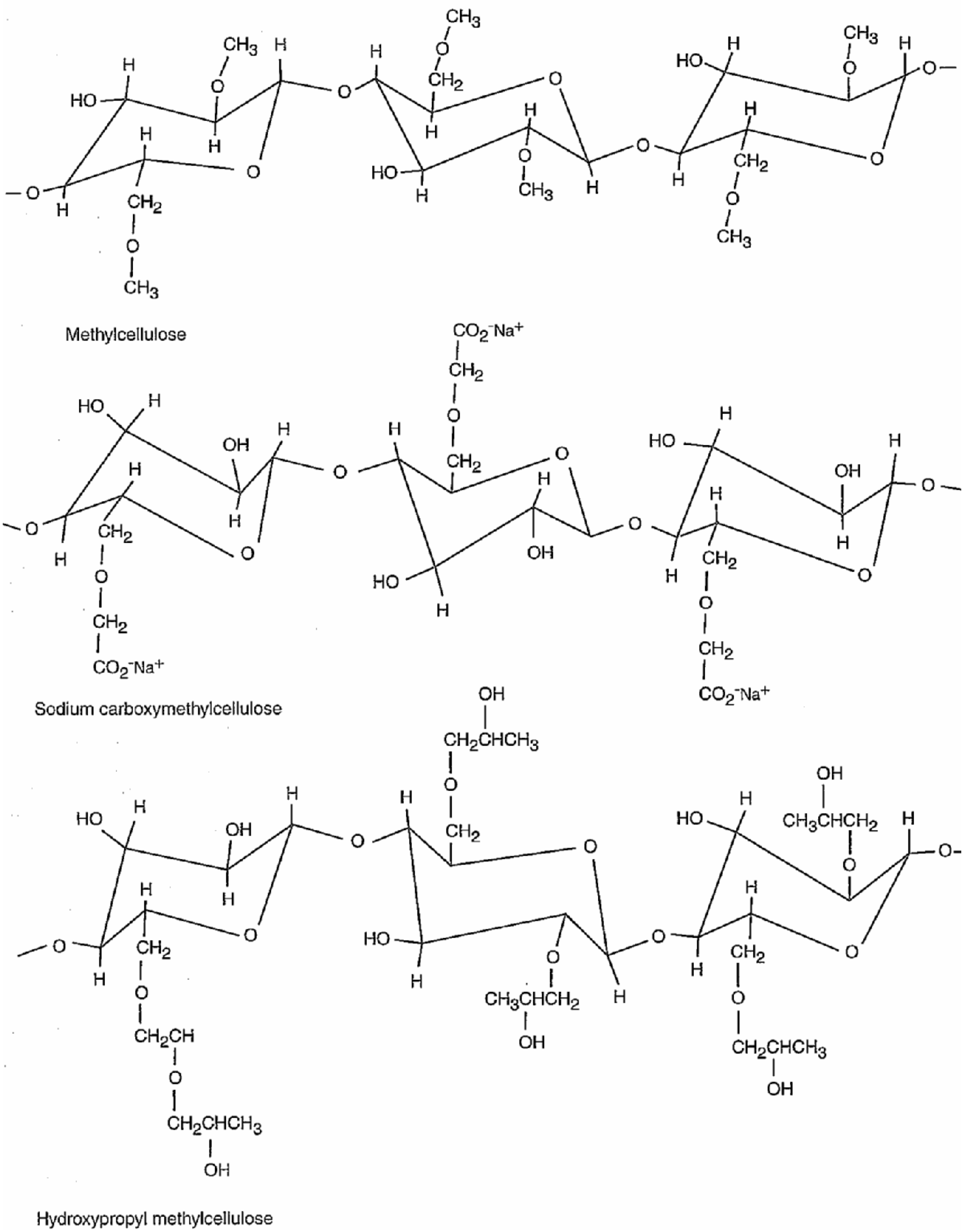
Cellulose is beta (1→4) glucan. For those less familiar with this terminology, these are glucose molecules that are linked C1 (carbon 1) to C4 utilizing the beta orientation (beta linkages described in Chapter 3). This linkage is in contrast with the alpha linkage of traditional starches;

in fact it is the only major structural difference when comparing the two molecules. The enzymes of the human digestive system are not capable of breaking this beta linkage. However, certain enzymes are capable of this conversion. In laboratory settings, cellulose can by hydrolyzed by heating in the presence of a strong acid. Cellulose is a major structural component for almost all plants and is believed to be the most abundant organic substance in the world (Morse, 1978). Cellulose varies in its morphology depending on its source, thus allowing a trained microscopist to be able to determine the plant of origin (Morse, 1978). Scientists recommend using cellulose as a fiber source because it is cheap, abundant, almost 100% dietary fiber, has low flavor impact, good storage stability, low or no microbe counts, and is a virgin product (Morse, 1978). Others would likely note its lack of functional viscosity (insoluble fiber) and its tendency to produce undesirable textural changes as reasons not to use cellulose.

Cellulose can also be modified by various further processing steps to change its structure and thus its functionality. One form of processing is to treat cellulose (sometimes referred to as alpha cellulose) with acid to remove the amorphous paracrystaline regions (Nelson, 2001). This is sometimes referred to as cellulose gel or microcrystalline cellulose. This ingredient can come in many forms and is mostly used for its thickening properties and sometimes as a carrier or bulking agent for various other ingredient or flavor delivery systems.

Cellulose can be chemically modified into methylcellulose, carboxymethylcellulose, or hydroxypropyl methylcellulose (Nelson, 2001). These molecules have a variety of substitutions that impact the molecules solubility and other physical properties. These molecules are shown in Figure 7.3.

Figure 7.3 Structures of Methyl, Carboxymethyl, and Hydroxypropyl Methyl Cellulose (Nelson, 2001)



Cellulose is known to significantly increase fecal bulk (and thus presumably laxation), decrease transit time, and increase wet stool weight (NAS, 2005). There is little, if any, effect of cellulose on blood lipid concentration or blood glucose responses, and is thus often used as a control or placebo in these types of studies (NAS, 2005).

Chitin/Chitosan

Chitin and chitosan are beta (1→4) linked insoluble polysaccharides that are found in arthropods (crabs or lobster) and some fungi and yeasts and is the second most abundant polymer in nature (second to cellulose)(NAS, 2005; Nelson, 2001). Chitosan is simply a deacylated version of chintin (Nelson, 2001). This fiber is available commercially and consumed as a supplement.

Chitin and chitosan have been shown to effect blood glucose concentrations in animal studies, although these results have not translated to human trials all that convincingly (NAS, 2005). NAS (2005) states there are no known reports that demonstrate that either of these fibers can affect blood glucose response or fat absorption in humans.

Corn Bran

Corn bran can be separated via wet or dry corn milling, separating the bran, germ, and endosperm components of the corn grain. The typical composition of the corn kernel is 80-85% endosperm, 10-12% germ, and 5-6% bran (Nelson, 2001). A variety of products are made from this process including grits, meal, flour, and bran (Burge and Duensing, 1989). Refined corn bran typically has a nutritional profile similar to the following: 4% moisture, 3.8% protein, 1% oil, 1% ash, and 88% total dietary fiber. The 88% fiber breaks out as 18% cellulose, 67% hemicelluloses, <2% lignin, <1% pectins, <1% gums and thus is largely insoluble fiber (Burge and Duensing, 1989). Corn bran is natural, minimally processed, low calorie, exhibits high water binding capacity, available in many grind sizes (to alter textural attributes), and is readily available. Burge and Duensing (1989) also cite studies which indicate corn bran helps reduce serum cholesterol (even without much soluble fiber) and the ability to absorb fecal mutagens, potentially protecting the body against them.

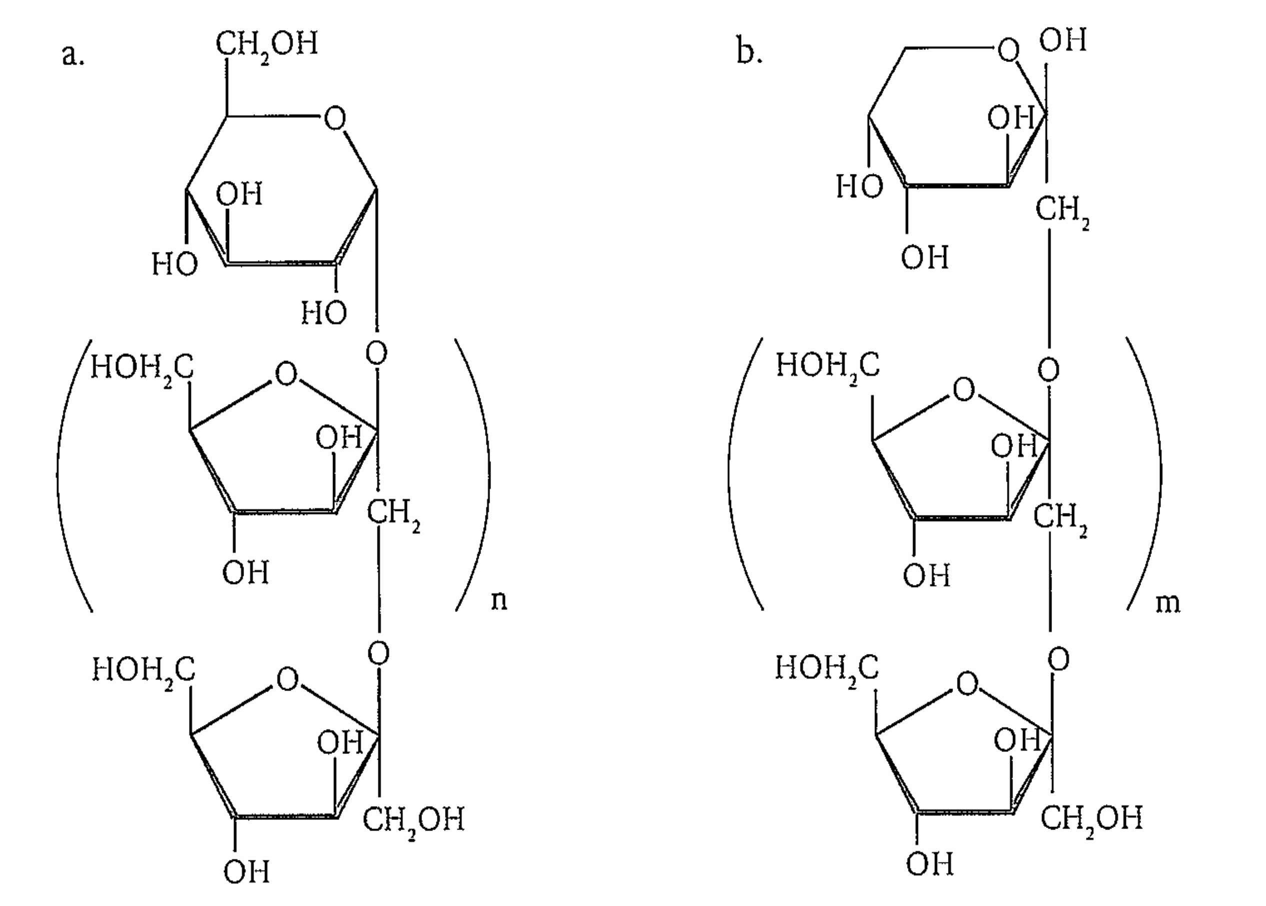
Corn Fiber

Corn fiber is the seed coat and residual endosperm from grain processing, often the by-product of wet milling used in the production of ethanol (Akin and Rigsby, 2007). This product is no longer readily available in the United States (Nelson, 2001). Research is being conducted to make this industrial by-product available for use as a biofuel (Akin and Rigsby, 2007).

Inulin

Inulin is a soluble fiber and is classified as a fructan. Inulin is composed of a linear chain of fructose molecules ending with a glucose molecule. This chain is made up of beta 2→1 linked fructose molecules and the chain length varies between approximately 2 and 60 units (Salovarra et al, 2007). Figure 7.4 shows Inulin's structure.

Figure 7.4 Structure of Inulin With (a) and Without (b) the Terminal Glucose Residue (Salovarra, et al., 2007)



The physical properties of inulin change slightly based on the chain length. Inulin is present in more than 36,000 plants and vegetables (Nelson, 2001). It acts as the energy storage system (instead of starch) for these plant species and is found in leeks, onions, garlic, asparagus, Jerusalem artichokes, dahlias, yacon, and chicory (Franck 2002; Westerdijk 1997). Chicory roots are the most widely used source as this plant has a very high content of inulin, up to 80% of the dry matter (Grühn, 1994). De Leenheer (1996) summarizes the inulin content of various sources of inulin in Table 8.

Table 8 Inulin Content of Commonly Consumed Plants (De Leenheer, 1996)

Source	Edible parts	Dry solids Content (%)	Inulin Content (%)
Onion	bulb	6-12	2-6
Jerusalem Artichoke	tuber	19-24	14-18
Chickory	root	20-25	15-20
Leek	bulb	15-20*	3-10
Garlic	bulb	40-45*	9-16
Artichoke	leaves-heart	14-16	3-10
Banana	fruit	24-26	0.3-0.7
Rye	cereal	88-90	0.5-1*
Barley	cereal	NA	0.5-1.5*
Dandelion	leaves	50-55*	12-15
Burdock	root	21-25	3.5-4
Camas	bulb	31-50	12-22
Murnong	root	25-28	8-13
Yacon	root	13-31	3-19
Salsify	root	20-22	4-11

NA : figures not available, * estimated

In practice, inulin is usually sold as a finely ground white powder. It is essentially odorless. In solution, inulin imparts some viscosity, slight opacity, and potentially a slight sweetness that is approximately 10% as sweet as sugar (Franck 2002). There are actually two types of inulin sold, standard and high performance or long chain. High performance inulin has had the shorter chains removed and thus has much less sweetness and results in greater viscosity in solution.

Inulin is used in a wide variety of products and for a number of reasons. Most common is fiber fortification, but it is also used to mimick fat, provide viscosity, stabilize gels/foams/emulsions, provide body/mouthfeel, freeze thaw stability, provide synergy with other sweetners, moisture retention, and as a prebiotic (Franck, 2002). Inulin is known to work synergistically with high potency sweetners to enhance their sweetness, reduce bitter off flavors, and enhancing fruity aromas (Grühn, 1994). Inulin can also be viewed as a prebiotic as it is consumed by the healthy microflora in the small intestine resulting in growth of those microflora, leading to a healthier bowel (Alldrick, 2000).

Inulin and other fructooligosaccharides have been shown to increase fecal bulk and reduce transit time while promoting the growth of bifidobacteria (NAS, 2005). Bifidobacterial are believed to promote health in animals, although the affect in humans it still unclear. The effect of inulin and other fructooligosaccharides is somewhat conflicted in the areas of blood lipid concentration and blood glucose response (NAS, 2005).

In industry, it is pretty widely understood that inulin has the tendency to result in increased flatulence in some people. Due to this, the amount used in products needs to stay at reasonable levels and people who are significantly affected by this are advised to read labels carefully for inulin or chicory root fiber.

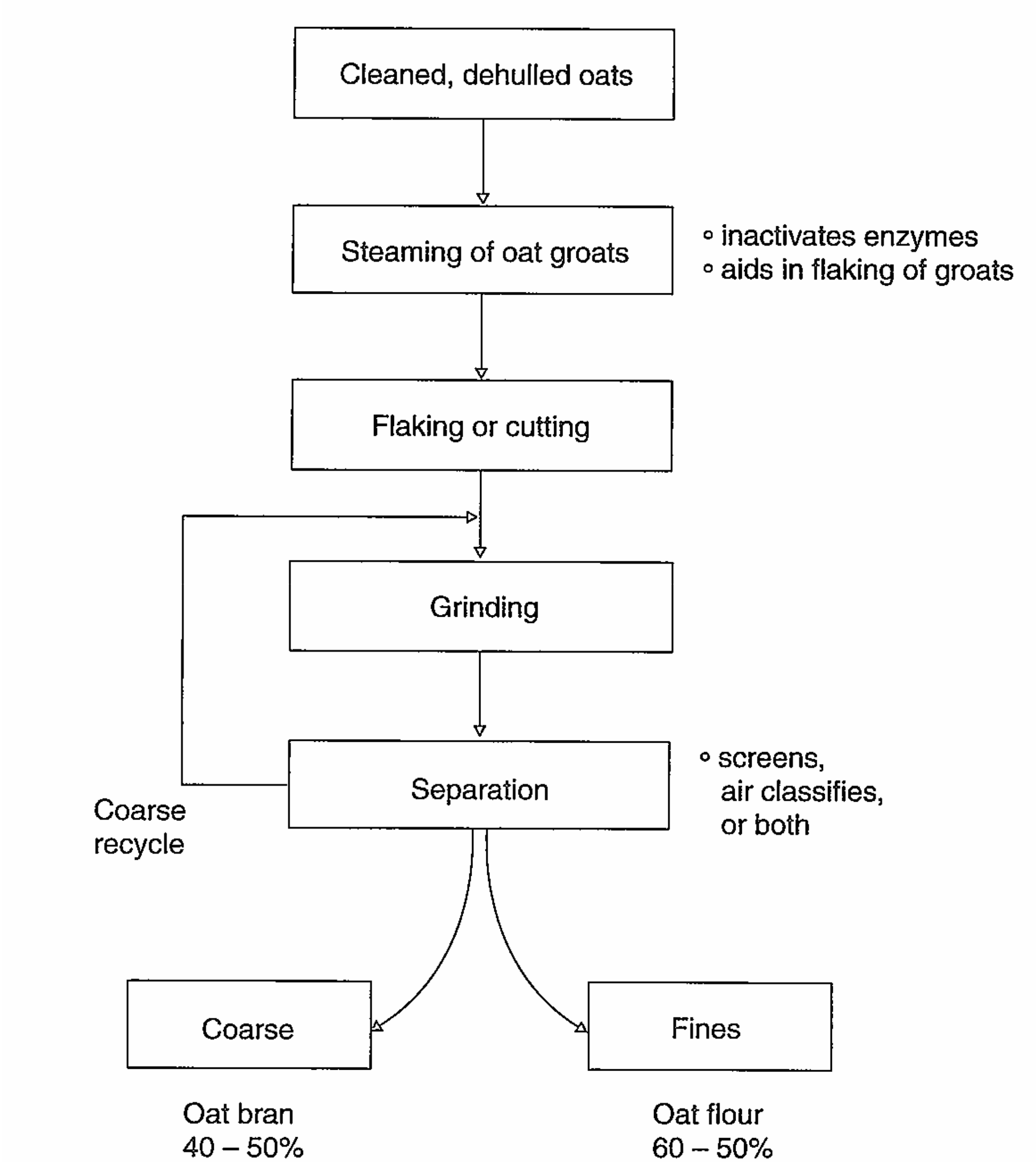
Oat Bran/Oat Fiber

When processing oats, the hulls are removed from the grain and separated via air classification and/or sifting (Figure 7.5). What remains (the oat bran, germ, and endosperm) is commonly called a groat. The hulls can be ground to produce oat fiber or they can be further processed to increase the fiber content and remove any unwanted fractions such as the color (Nelson, 2001).

Groat can be further processed to yield oat bran and oat endosperm. Oat bran is composed of the bran and endosperm because it is quite difficult to remove the endosperm from the bran compared to other cereal grains, likely due in part to the high lipid content (Nelson, 2001; Fulcher and Miller, 1993). Oats are a significant source of beta glucan, which is predominantly a cell wall component of the oat endosperm (Fulcher and Miller, 1993).

Oat bran is typically made up of 16-32% dietary fiber, although some are further refined to contain dietary fiber as high as 90% (Nelson, 2001). The ratio of soluble to insoluble fiber varies greatly based on the initial composition and the level of refinement, but at least one third of the fiber must be soluble based on the definition of oat bran from the AACC. AACC also requires that oat bran contain at least 5.5% beta glucan (Nelson, 2001).

Figure 7.5 Oat Bran Production Process (Nelson, 2001)



Oat products are associated with a host of beneficial effects in humans, many directly related to the beta glucan present. Insoluble fiber from oats can help with fecal bulk and transit time, while the soluble fiber (including beta glucan) is believed to promote bacterial growth in the large intestine through fermentation, lower blood lipids, and reduce glucose response, although some conflicting research is also available (NAS, 2005).

Pea Fiber

Pea fiber is made from the shells of peas. In practice, the powder can be white to green, depending on pea source and any purification that is done (Nelson, 2001). Nelson states that pea fiber is typically 75-82% fiber, 77% of which is insoluble.

Pea fiber from the inner cell walls can be used to alter the sensory properties of reduced fat beef patties (Anderson and Berry, 2000). This fiber contains approximately 48% fiber, 44% starch, and 7% protein. This study determined patties with pea fiber had higher yield and improved tenderness, similar juiciness, but slightly less beef flavor and more browned flour flavor.

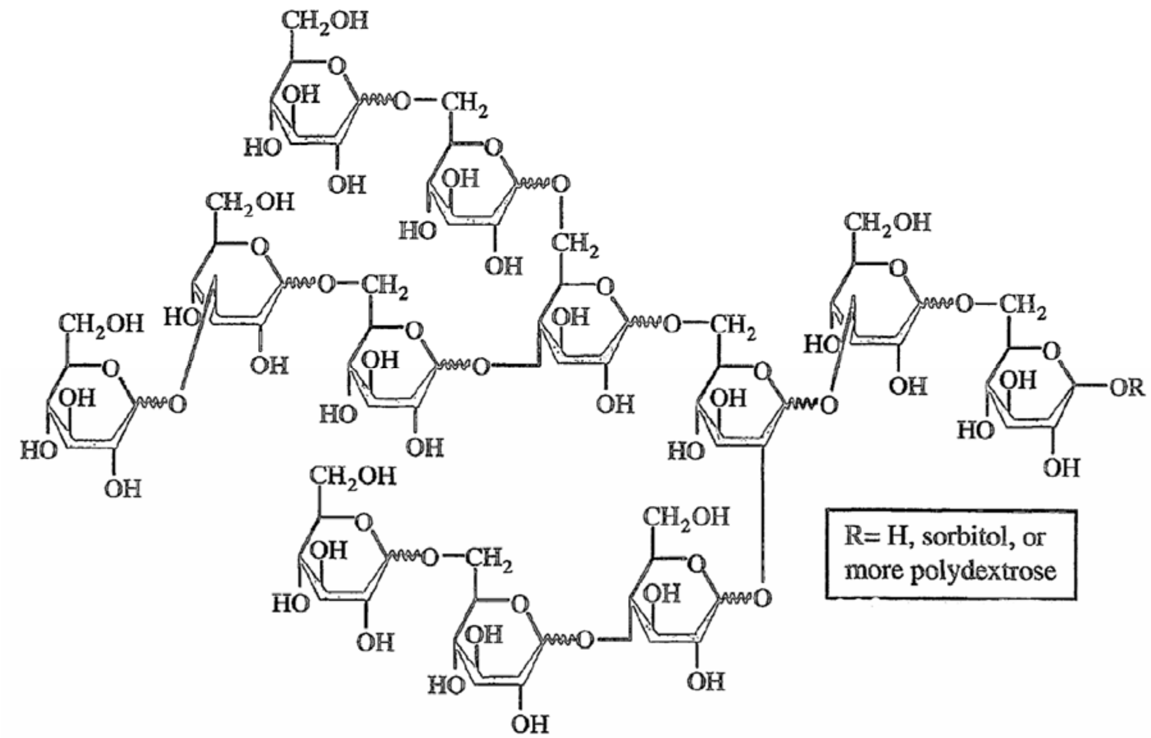
Pectin

As stated in Chapter 3, pectins are linear chains of glacturonic acid with some rhamnose units included in the chain. Pectin does not seem to have a significant effect on fecal bulking, wet stool weight, or transit time, but is believed to reduce blood glucose response (as other viscous fibers do) (NAS, 2005). NAS also states that most studies indicate pectin provides a lowering effect on blood lipid concentrations, particularly to LDL (or "bad") cholesterol.

Polydextrose

Polydextrose is a polymer of randomly ordered glucose and sorbitol units (NAS, 2005). This molecule is not sweet and considered a resistant oligosaccharide or polysaccharide (Nelson, 2001). The structural complexity and tightness is the reason it resists the action of enzymes, although some of it is available to the enzymes, resulting in approximately 1 kcal per gram energy compared to 4 kcal per gram for a fully available starch (Craig et al, 1998). It is often used as a bulking agent and a source of dietary fiber in many food products. According to Nelson (2001), it has a neutral flavor, is stable, and very water soluble. Polydextrose can be used by food industry professionals to supplement fiber, replace fat, or replace sugar. Figure 7.6 shows the chemical structure of polydextrose.

Figure 7.6 Structure of Polydextrose (Nelson, 2001)



Polydextrose is believed to have several physiological effects related to laxation. Increased fecal mass has been shown, although the effect on transit time and fecal bacterial production are not well agreed upon as studies conflict (NAS, 2005). Polydextrose lowers the pH of the intestinal contents, resulting in the promotion of beneficial bacteria (probiotic effect) and inhibiting pathogenic bacteria (Craig et al, 1998).

Polydextrose is generally regarded as a safe food ingredient in the United States and throughout most of the world. Japan allows a health claim- provides improved intestinal function- with the use of this fiber (Craig et al, 1998). However, as Craig et al state (1998), the United States is one of 5 countries that require a laxation statement on foods that contain more than 15g polydextrose per serving. This regulation discourages using too much polydextrose in formulated products and somewhat protects people that might be sensitive to significant intake of this ingredient.

Polydextrose, like many oligosaccharides and other molecules thought to act as dietary fiber, is not captured in the typical analysis of foods for dietary fiber, such as the AOAC method 993.21 for total dietary fiber (Craig et al, 1998). Special analysis methods are needed to quantify this portion of dietary fiber in food products, as discussed in Chapter 5.

Psyllium

Psyllium (or psyllium husk/ispaghula husk) is a soluble fiber derived from the husk of psyllium seeds (NAS, 2005). This fiber source is about 70% soluble fiber and is a polymer of arabinose, galactose, galacturonic acid, and rhamnose (Nelson, 2001)

Psyllium's role in laxation is well known as it is commonly used in laxatives and has been shown to increase stool water content and water weight, total stool output, bowel movement frequency, and thus reduce the issues of constipation (NAS, 2005). Psyllium has been shown to reduce blood lipid concentration, most often more so on total and LDL cholesterol and less on HDL, and blood glucose responses in a wide variety of studies (NAS, 2005).

Resistant Starch

Resistant starch, as explained in Chapter 3, is comprised of starch molecules that are unavailable for degradation for a variety of reasons and are classified as RS1 through RS4. Total dietary fiber of resistant starches that are available for purchase can range from 1-40% (Nelson, 2001).

Although the physiological effects of resistant starch varies by what type it is, generally resistant starch is believed to slightly increase fecal bulk, reduce blood glucose response, and have little effect on blood lipid concentration (NAS, 2005). After passing through the small intestine, this starch is fermented in the large intestine, producing short chain fatty acids. Contrary to the contentions of the NAS, Leszczyński (2004) describes the short chain fatty acid production as having several beneficial effects in the colon. These effects include reduction of blood lipids and cholesterol, promotion of favorable intestinal microflora, and prevention of gut cancer. Based on these and other sources, there is some disagreement on the role of resistant starch within the body.

For practical purposes, resistant starch that is added to food products in industry can be produced from any of the starch types (RS1-RS4). These starches resist the action of amylase enzymes by essentially blocking the enzyme from getting onto the starch chains to begin the process of cleaving of glucose units (Leszczyński, 2004). Leszczyński also explains a process of dextrinization where the starch is heated in a variety of conditions to allow a re-working of the starch molecules and bonding. The result is various dextrins that have physical structure and bonding that is not accessible to the amylase enzyme. A variety of these techniques are used in industry to create resistant starch, much of which is seen as proprietary information.

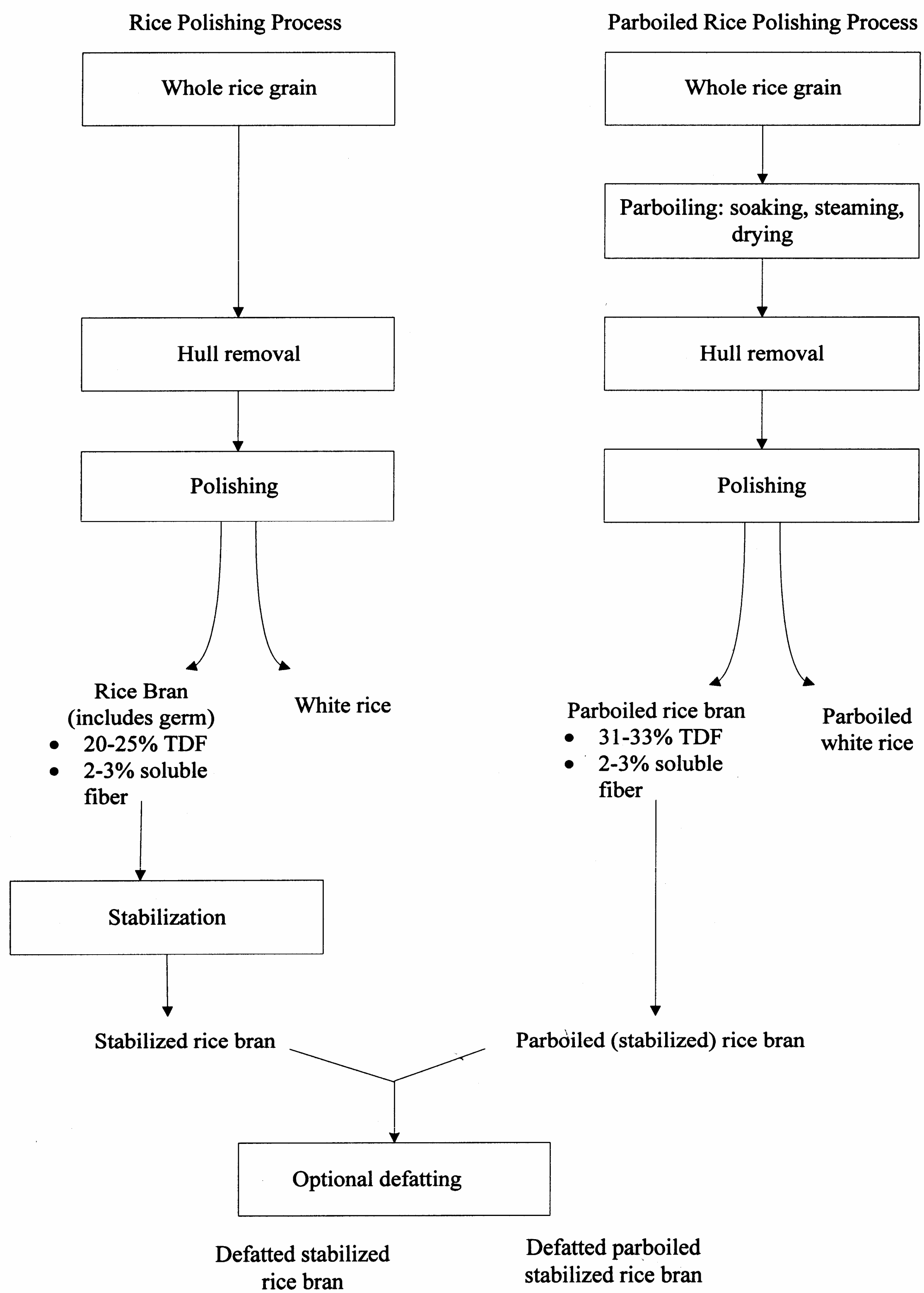
Rice Bran

Rice bran is obtained when making white rice. Once the hull is removed, the rice bran is obtained by further processing and abrasion (called polishing) to separate the bran and germ portions from the endosperm (Nelson, 2001). The total dietary fiber content of rice bran varies based on whether it is obtained from standard whole grain rice or from parboiled rice. Note the percentages on Figure 7.7, but generally rice bran contains 20 to 33% dietary fiber, the vast majority of which is insoluble.

Rice hulls are about 25% of the initial rice grain and contain mainly cellulose and lignin (Saunders, 1986). Apparently rice hulls have little commercial use based on literature review. Rice bran is mostly used as animal feed as the high lipid content (as well as protein, vitamins, and minerals) leads to rancidity and thus off odors and flavors (Saunders, 1986; Nelson, 2001). Rice bran, therefore, finds limited commercial use in foods, although it can be found in rice flours and breakfast cereals (Saunders, 1986).

Figure 7.7 shows the process of polishing for standard and parboiled rice. Note the need for a stabilization step in the case of standard rice, as the lipase enzymes need to be inactivated to eliminate rancidity issues in the oil portion of rice bran. The bran from either process can be defatted as a further purification step.

Figure 7.7 Rice Bran Production Process (Nelson, 2001)



Soy Fibers

Soy can be processed into three fiber ingredients- soy bran made from hulls, soy fiber made from endosperm called cotyledon, or soy protein concentrate/isolate also made from cotyledon (Nelson, 2001; Riaz, 2001). Soybean cell walls are made up of approximately 30% pectin, 50% hemicelluloses, and 20% cellulose (Riaz, 2001). This makeup will vary based on what part of the soybean is analyzed.

Soy bran is made from the soybean hull and is typically 65 to 95% total dietary fiber and is mainly insoluble. Hulls are further refined to accomplish this level of purity, involving lipid extraction, and the product of that is ground to various sizes (Nelson, 2001).

The process of making soy protein concentrates results in the generation of the other two fiber sources. This process involves taking the dehulled soybeans and further processing them by rolling, lipid extraction, drying, and finally protein extraction (Riaz, 2001). The protein extraction involves a solubilization step at alkaline pH that removes most of the protein and some soluble fiber; this fraction will become soy protein concentrate. The non-solubilized portion will become soy fiber. Both products are somewhat purified and then dried.

Soy fiber is typically a total dietary fiber content of 75-80%, which is a mix of insoluble and soluble dietary fiber, and contains much less cellulose derived than the bran fraction (Nelson, 2001). Soy protein concentrate is typically about 20% dietary fiber and 70% protein (Nelson, 2001).

Soy bran and fiber ingredients are used in all sorts of products that are currently in the market place. These products include many nutritional beverages (such as those used in hospitals), muffins, cookies, crackers, pudding, cake, noodles, breakfast cereals, snack foods, and more. Soy fiber can be used from 5-20% of the flour weight in multigrain breads or up to 10% in bakery products (Riaz, 2001). At these levels the product is certainly being impacted by the functionality of the fiber and it allows improved nutritional labeling by significantly increasing the amount of fiber in the product.

Soy fibers provide many of the typical health benefits of other soluble and insoluble fibers. These fibers have been shown to have many positive effects on bowel function including increased fecal bulk, decreased transit time, increased stool consistency, and increased frequency of bowl movements (Riaz, 2001; Slavin, 1991). Riaz also contends that soy fibers have been shown to reduce serum cholesterol, lower insulin and glucose responses, and reduce mineral absorption to a lesser extent than other fibers (this is a significant concern in some populations, not too often in healthy people consuming a well balanced diet).

Wheat Bran

Wheat bran is a by-product of wheat milling containing the outer layers of the wheat grain (Harris et al, 2005). It typically contains about 45% total dietary fiber, other components being protein, starch (contamination from milling process), moisture, ash and a variety of other low level fractions (Bollinger, 1996; Harris et. al., 2005). Wheat bran can be separated into two main fractions; the pericarp fraction which contains a greater proportion of the outer wall of the grain and the aleurone fraction that contains a greater proportion of the inner wall (Harris et al, 2005).

Consumption of wheat bran is associated with a wide variety of health benefits including relieving constipation and prevention of colorectal cancer (Harris et al, 2005). It is important to know that most studies focus on wheat bran as a whole, not its subsequent fractions, so what compounds are associated with each particular health benefit is not well known.

Wheat Fiber

Wheat fiber is essentially a further refinement of wheat bran. It is primarily cellulose and hemicellulose with very low levels of lignin (Bollinger, 1996). It can be labeled as wheat or plant fiber. This fiber has a light color, neutral taste/odor, high fiber content (~98%) thus low caloric value, high water binding capacity, dispersing effect, good storage stability, and a clean label. Bollinger describes wheat fiber's unique property of binding water compared to simple surface association, called the capillary affect, resulting in lower vapor pressure and positive product characteristics unique to this fiber, particularly in the case of wafer production. Wonderful baking properties of this fiber are described without undesirable sticking or discoloration.

Summary of Fiber Content of Various Sources

Many of the above descriptions include comments on the approximate fiber content of various ingredient sources found in each of the categories. Nelson (2001) summarized these and a few other ingredient sources of dietary fiber in Table 9.

Table 9 Dietary Fiber Content of Various Ingredient Sources (Nelson, 2001)

Source Category	Source Type	Ingredient	Typical TDF[a] Range (%)
Cereal grains	Oats	Whole oats/flour	~14
		Oat fiber	80–99
		Oat bran	16–32
		Other oat ingredients (high β-glucan)	~10–15
	Wheat	Whole wheat/flour	~12
		Wheat bran	34–45
		Wheat germ	10–20
	Barley	Barley flour	~10
		Barley bran	18–50
		Barley bran flour/brewer's spent grain	35–70
	Rye	Whole rye flour	15–17
		Rye bran	~25
	Rice	Rice bran	20–35
	Corn	Corn bran	50–65
	Soy	Soy hull fiber	65–95
		Soy cotyledon fiber	~75
		Soy protein concentrate	~20
	Other grains	Amaranth, flax seed, spelt, kamut, etc.	10–15
Plant-derived	Bamboo, wood, cottonseed, etc.	Cellulose	80–99
	Modified cellulose	Microcrystalline cellulose	80–99
		Methylcellulose	80–99
		Sodium carboxymethylcellulose	80–99
		Hydroxypropyl methylcellulose	80–99
	Gums		
	Seaweed extracts	Carrageenan, alginates	80–90
	Plant extracts	Gum acacia (gum arabic), gum karaya, tragacanth gum	80–90
	Seed extracts	Guar gum, locust bean gum	80–90
	Microbially fermented	Xanthan, gellan, pullan	80–90
	Chicory roots, Jerusalem artichoke, etc.	Inulin and fructooligosaccharides	~90
	Konjac tuber	Konjac flour	~95
	Peas, outer shell	Pea fiber	75–85
	Potatoes, corn, etc.	Resistant starch	1–40
	Sugar beets	Sugar beet fiber	~75
	Western larch tree	Arabinogalactan	~80–95
	Psyllium seed coat	Psyllium	~80
Fruits	Prunes, dates figs, raisins	Whole or fruit pieces	5–8
		Powder	10–65
	Apple, pear	Powder	20–70
	Apple, citrus	Pectin	50–80
Other	Shellfish	Chitin/chitosan (modified chitin)	~80
	Bacterial fermentation	Curdlan (insoluble β-glucan)	~95
	Synthetically produced	Polydextrose	~95

[a] Total dietary fiber.

Table 10 displays grams of fiber in common foods. Note that values are rounded as they would be on a nutritional label.

Table 10 Grams of Total Dietary Fiber in Common Foods (Duyff, 1996)

Counting Up Fiber

How much fiber do these common foods supply?

	Amount	Fiber* (grams)	Calories
Fruits			
Apple (w/skin)	1 medium	3	80
Applesauce	1/2 cup	2	55
Banana	1 medium	2	105
Blueberries	1/2 cup	2	40
Cantaloupe	1 cup	1	60
Figs, dried	2	4	95
Grapes	1/2 cup	1	30
Orange	1 medium	3	60
Orange juice	3/4 cup	<1	75
Peach (w/skin)	1 medium	1	40
Pear (w/skin)	1 medium	4	100
Prunes, dried	3	2	60
Raisins	1/4 cup	2	115
Strawberries	1 cup	4	45
Vegetables, cooked			
Broccoli	1/2 cup	2	25
Brussels sprouts	1/2 cup	3	30
Peas	1/2 cup	2	65
Potato, baked (w/skin)	1 medium	4	200
Potato, mashed	1/2 cup	1	110
Spinach	1/2 cup	2	20
Sweet potato, baked (w/skin)	1/2 medium	2	60
Zucchini	1/2 cup	1	20
Vegetables, raw			
Carrots	1 medium	2	30
Celery	1 stalk	<1	5
Cucumber, sliced	1/2 cup	<1	5
Lettuce, romaine	1 cup	1	10
Mushrooms, sliced	1/2 cup	<1	10
Spinach	1 cup	1	10
Tomato	1 medium	2	30
Legumes, cooked			
Baked beans, plain or vegetarian	1/2 cup	3	120
Kidney beans	1/2 cup	3	115
Lentils	1/2 cup	4	115
Breads, grains, and pasta			
Bagel	1 medium	1	165
Bread stick	1	<1	115
Brown rice, cooked	1/2 cup	2	110
French bread	1 slice	<1	80
Pumpernickel bread	1 slice	3	80
Spaghetti, cooked	1/2 cup	1	100
Wheat bran	1 tablespoon	2	10
Wheat germ	1 tablespoon	1	15
White bread	1 slice	<1	60
White rice, cooked	1/2 cup	1	135
Whole-wheat bread	1 slice	2	60
Breakfast cereals			
100% bran	1/3 cup	8	70
Bran flakes	3/4 cup	5	90
Corn flakes	3/4 cup	1	100
Granola w/raisins	1/4 cup	2	130
Oatmeal, cooked	3/4 cup	3	95
Raisin bran	3/4 cup	5	120
Snack foods			
Hummus dip	2 tablespoons	2	50
Peanuts, dry-roasted	1/4 cup	3	215
Popcorn, air-popped	1 cup	1	30
Sunflower seeds	1/4 cup	2	210
Walnuts	1/4 cup	1	95

**Due to the different methods used in determining fiber in foods, fiber values found on Nutrition Facts panels and in other sources of fiber information may vary slightly from those listed.*

Note: Nutrient values are rounded.

Sources: Bowes & Church's Food Values of Portions Commonly Used, 16th Edition, 1994; Plant Fiber in Foods, 2nd Edition, 1990; *and manufacturer data.*

Considerations for Fiber Use in Product Development

Many things must be considered when evaluating potential fiber sources to be used in product development. These considerations include cost, consumer perception/labeling, handling and storage requirements, sensory characteristics, stability, starting usage levels in the product, and effect on water activity. Each product is different and all product development opportunities present unique challenges, this is partly what makes this work so challenging and exciting.

COST: Cost is an important consideration in all aspects of product development. Regardless of how good a product formulation could be, the business must make money in order for the product launch to be viable. Thus there is a difficult balance of achieving an ingredient cost that allows money to be made on the sale of the product, yet product quality is high enough that most consumers purchase the product repeatedly. Certainly the fibers described in this report vary widely on cost. One must keep these restraints in mind when choosing potential fiber sources.

CONSUMER PERCEPTION/LABELING: Certain ingredients have positive or negative consumer perceptions. Monosodium glutamate is a great example of this- has a negative consumer perception but little evidence exists that supports any claim of ill effects from this flavor enhancer. Similarly one should consider how the ingredient will label in the product ingredient statement. Consumers that read labels dislike things they cannot pronounce and may have heard bad things about, whether it is the truth or not. All of the fiber sources on this list are GRAS (Generally Recognized As Safe) for food use and should be relatively label friendly.

HANDLING AND STORAGE REQUIREMENTS: Ingredients can come in a variety of forms- powdered, liquid, solid- and require a variety of storage conditions to maintain their freshness, such as refrigeration, freezing, low light, and control of relative humidity. Generally plants prefer to use powdered ingredients that can be stored at room temperature. Ingredients in the liquid or solid form can be difficult to deal with and can require more costly temperature controlled storage. It is a good idea to visit your probable production location and determine the types of ingredients that can and cannot be used in the product.

SENSORY CHARACTERISTICS: Each fiber source, and even the same fiber source from a different manufacturer or process, has its own unique set of flavor, textural, and functional characteristics. For example, pea fiber often has some residual flavor of peas, or perhaps cooked or burned peas. This may be acceptable in certain products at reasonable usage levels but not acceptable in others.

STABILITY: Stability of an ingredient is important, both in its ingredient form and in the finished product. Production locations like ingredients that are easy to use and have a shelf life of at least six months. Similarly, the ingredient must be stable in the product and through the processing that takes place to make the product. In the case of retorting, the heat (along with presence of acid) can cause some of the fiber to be broken down, thus reducing the overall fiber in the product. Enzymatic activity can similarly reduce fiber if given time to act upon the fiber molecules. Finally, properties of the final product can impact the stability of the fiber ingredients. These changes can be monitored by quantifying the dietary fiber in product at various stages of production and at specific time intervals to see if that value is changing.

STARTING USAGE LEVELS: Recommending usage levels for products is completely dependent upon the fiber being used, the product it is being used in, and the development goals for that product. Leverage suppliers for recommended starting usage levels, as they should be the experts on how their ingredient will perform in food systems. Also, consider covering a wide range of usage levels early in the development cycle so that it is clear what impact the fiber will have on the product and generalized conclusions can be made concerning maximum usage levels. For a product wanting to supplement fiber to a specific level, add the amount that would be required to attain that fiber quantity and evaluate the product. Sometimes a mix of several different fibers will result in appropriate functionality in the product and desirable product characteristics. This process can be iterative until the product scientist becomes familiar with the fiber types and their functionality in various food systems. Keep in mind that too much dietary fiber, particularly somewhat abrupt changes in fiber consumption, can result in undesirable effects such as constipation, diarrhea, gas, or bloating.

WATER ACTIVITY: Addition of many of the fiber sources listed above will result in a change in water activity in the product. In products that are greatly impacted by water activity, an example being chewy granola bars, this change may influence product acceptability, stability, and shelf-life. It is important to have a firm grasp of the role of water activity in products that are greatly affected by it.

CHAPTER 8 - Summary

Currently, dietary fiber is a topic of considerable interest and debate. Unlike many other components of foods, the importance of dietary fiber was not well established until sometime in the 20th century. Prior to this, only a few times in recorded history was dietary fiber referenced as having beneficial effects within the body. As mankind has progressed and foods have become increasingly refined to improve their eating quality, much of the dietary fiber naturally present is being removed.

Dietary fiber does not have one definition that is widely accepted among the scientific community, although current research and debate seem to be driving this issue forward. Most definitions reference dietary fibers being undigestible by human enzymes and metabolic processes, many refer to polysaccharides, and some state that fiber must come from plant sources. Relatively recently a new term has emerged, functional fiber, that traditionally has not been quantified by analytical techniques for dietary fiber, yet these molecules exhibit similar beneficial effects in the body. Recent advances in fiber isolation technologies have given rise to many new fiber ingredients, many of which are considered functional fiber.

Dietary fibers can be divided into several groups of compounds: pectins, cellulose, hemicelluloses, lignin, hydrocolloids, mucilages, and resistant starches. A significant part of the complexity in defining dietary fiber is trying to account for the wide variety of compounds that act as dietary fiber. More generally, fiber is often grouped into soluble and insoluble portions, although recently functional fiber has been added to these groups as many compounds thought of as dietary fiber do not analyze as soluble or insoluble fiber based on traditional methods.

Lack of dietary fiber consumption is associated with the development of many common diseases through epidemiological and human/animal intervention studies. These diseases include (but are not limited to) bowel disease/Crohn's disease, colon cancer, constipation, diabetes, diverticulosis/itis, gallstones, heart disease, high cholesterol, hyperlipidemia, and obesity. While very strong epidemiological evidence exists, cause and effect conclusions cannot be made based upon these studies alone. Epidemiological studies cannot determine if the presence of dietary fiber is the reason for the health effect or if foods high in fiber are generally more nutritious than those low in fiber and that is the reason for the health benefits. In any case, strong associations are made based on these studies and this evidence cannot be ignored. Intervention studies often have mixed or conflicting results, although some areas have been studied enough to support the beneficial effects of dietary fiber in combating some diseases. These studies are expensive and difficult to execute and dietary fiber had not been a focus of much research until the mid 1900's or so. Thus there is still a great need for research correlating specific fiber types to reduction in disease risk.

Dietary fiber is subject to the Nutritional Labeling and Education Act and is a mandatory field on nutritional labels. Various content claims, such as high fiber, and health claims, such as reduced cancer risk, are approved for use in products that do not contain disqualifying levels of fat, saturated fat, sodium, or cholesterol.

There are many ingredients that are used to supplement fiber in food products. Often these ingredients impart some other functional or flavor impact to the product as well. These come from a wide variety of sources and vary greatly in their impact on food products. When choosing which of these ingredients to use, food product developers must balance cost, functionality, flavor impact, labeling, and process-ability. Each fiber ingredient has its own unique set of characteristics.

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