CHAPTER 5

Dietary Fibers in Modern Food Production: A Special Perspective With β-Glucans

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1 Introduction

Dietary fiber has been variably defined by researchers in various eras but most of the researchers claimed it as a plant part that resists digestion against gut enzymes in human beings. Chemically, these plant parts are composed of homopolysaccharides, heteropolysaccharides, resistant starches, oligosaccharides, lignin, gums, and mucilages. On the basis of water solubility, these can be grouped into two classes: soluble and insoluble dietary fibers (SDF and IDF). Plant cellulose, hemicellulose, and lignin material are categorized as IDF and provide structural strength to plant material, whereas, gums, mucilages, pectins, β-glucan, galactomannans, and glucomannans are considered as soluble fibers and have gel formation capacity (Brown et al., 1999; Rodriguez et al., 2006). Variable chemical composition of dietary fiber is the major hindrance in defining dietary fiber. This variability in composition is also responsible for variability in physiochemical parameters of dietary fibers, such as viscosity, water-binding capacity, foaming capacity, solubility, fat-holding capacity, swelling, and fermentation capacity (Elleuch et al., 2011; Mudgil and Barak, 2013).

A lot of health benefits and physiological responses are related to consumption of dietary fibers. This may include laxation, blood glucose and cholesterol reduction, and lower risk of colon cancer. Consumption at adequate levels also regulates intestinal transit and glucose absorption into the blood, and heart-related problems and serum triglycerides drop (Ahmad and Ahmed, 2011; Kaczmarczyk et al., 2012; Kendall et al., 2010) thus providing beneficial effects for hyperlipidemia, hypercholesterolemia, and hyperglycemia (Kaczmarczyk et al., 2012). The majority of the health benefits of dietary fibers are source based. Fungal and bacterial dietary fiber in the form of β-glucan is valuable against viral infections, tumors, and bacterial invasion. Based on these and other numerous health benefits, consumers often

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prefer to consume the dietary fibers as nutraceutical food supplements. Plenty of dietary fiber supplements are present in the market; they claim laxative properties and better gut health. However, it is always advisable to look for physiological benefits and personal conditions before use of such supplements (Ahmad et al., 2010, 2012a,b).

Dietary fiber extraction can be achieved through various sources, and a lot of sources for dietary fibers have been identified. Predominantly, plant parts are the major sources but their extraction is not limited to plant sources. Various fungi, mushrooms, bacteria, yeast, and algae are considered good sources because some members from this group have an ability to produce exopolysaccharides (EPS) of variable nature that can be used as dietary fibers. The chemical nature and properties of these fibers differ remarkably. Much of the dietary fibers from these sources are composed of cellulosic polysaccharides, galacturonic acids units, gluco- and galactomannans polysaccharide units, and hemicellulosic polysaccharides. Lignin is perhaps the only nonpolysaccharide material present in these dietary fibers. These polysaccharide substances are linked together either in straight chains are in branched chains (Ahmad et al., 2012a; Anderson et al., 2008).

Extraction of dietary fiber in its purified form is a complex process and requires a lot of expertise to achieve a high level of purification. Various techniques for extraction of dietary fibers are in use but most of these techniques are based on three vital steps, including inactivation of indigenous enzymes, dietary fiber extraction, and dietary fiber precipitation. Extraction yield is also dependent on the choice of solvent and extraction condition. Water, acetone, ethanol, methanol, and their mixtures are often used for extraction purposes. Some researchers also used enzymatic extraction process. Recently, some researchers used physical means of extraction using ultrasonication techniques. Whatever is the extraction process, the role of extraction factors is not always completely clear. Thus, along with dietary fibers some other unwanted materials, depending on the chemical characteristics of the solvent, are also extracted, and the variable composition of the products require an efficient purification system that can remove undesirable components from dietary fibers (Ahmad et al., 2010; Hu et al., 2015).

A great deal of literature is available on defining dietary fiber and its analytical procedures, but still we do not have an acceptable definition of dietary fiber and this is still a topic of discussion among the experts in this field. Similarly, there is a history of analytical procedures for the determination of dietary fibers. These analytical procedures are based on the existing definition of dietary fiber. Researchers suggested different modifications in analytical procedures with time to meet the requirement of analysis per the definition of the dietary fiber (McCleary, 2011; McCleary et al., 2010). The awareness about the use of dietary fibers in food products is the driving force for the development of dietary fiber–based food products. Consumer are now conscious about their health, and the role of food in improving the quality of life necessitates that scientists and industries develop new functional foods (Ahmad et al., 2012a). Today, numerous food products are being produced with the inclusion

of dietary fiber. These may include baked items, dairy products, meat-based products, confectionaries, beverage products, pasta products, extruded products, and many more. There is a great trend of developing new food products for weight watchers and diabetic patients, and all of this is becoming possible by the use of dietary fibers in these food products (Ahmad and Anjum, 2010; Ahmad et al., 2008).

β-Glucan is a special kind of dietary fiber that can be obtained from cereal sources, mushrooms, algae, and bacteria, and it possesses numerous health benefits that may include better gut health, immunomodulation effect, antidiabetic properties, cholesterol-lowering effects, prevention against constipation and colon cancer, and a prebiotic effect. Among cereals, barley and oats are rich sources for cereal β-glucan that is characterized by β-(1→3) (1→4) linkages and is very effective for diabetic patients, weight-watchers, and hypercholesteremic patients. Bacterial β-glucan is available in various chemical forms that may have linear chains of glucose units linked together through (1→3) linkages, and sometimes these are branched having linear (1→3) linkages and branching originates as (1→2) linkages. Another form of bacterial β-glucan closely resembles fungal β-glucan, having (1→3, 1→6) linkages (Ahmad and Anjum, 2010; Ahmad et al., 2012a). This chapter will focus on the definition of dietary fibers in various eras, their classification, basic chemistry, analytical methods, extraction methods, health benefits, and food applications.

2 Definition of Dietary Fiber

The definition of dietary fiber has kept on changing over the decades. The first definition appeared in 1953 and defined dietary fiber as "indigestible food components from the plant cell walls" (Hipsley, 1974). At that time, its importance was not recognized because it did not contribute to the intake of calories. During this time, cellulose, hemicelluloses, and lignin, which are now considered vital fractions of crude fiber, were considered important for bowel function but devoid of calories (Giuntini and Menezes, 2011). The definition of dietary fiber remained in literature for about 2 decades; then modifications were introduced by Trowell (1976), and that was actually a more nutritional basis for this definition. He gave a concept that a fraction of food is comprised of polysaccharides and lignin, which resist the hydrolysis process by digestive enzymes present in human beings. According to details of this definition, many other compounds in addition to crude fiber may be included in the definition of dietary fiber. This definition of Trowell was accepted and prevailed for many years and was the driving force for the development of analytical procedures for the determination of dietary fibers. This was perhaps the most acceptable definition that prevailed for more than 2 decades. During this period some other definitions of dietary fibers arose on the horizon, but could not get accepted for a longer period of time in the 20th century. At the start of 21st century, again scientific debate on defining dietary fiber was initiated. This time, the debate was not initiated on an individual level but at the platform

of American Association of Cereal Chemists (AACC). A special committee was appointed on defining dietary fiber and an updated definition came in 2001, that defined dietary fiber as "edible plant parts and analogous carbohydrates that resist hydrolysis process by human digestive enzymes in the small intestine of human being but have a capacity of partial or complete fermentation in large intestine may be referred as dietary fibers" (DeVries, 2010). At the same time the Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) was also working on the definition of dietary fiber. They commented that the AACC definition may be slightly modified and should include edible parts from plant sources, as well as animal sources. This controversy has less evidence to support, as we know that most of the scientific evidence indicates plant sources as the origin of dietary fibers. At the same time, the World Health Organization (WHO) special committee on dietary fiber also recommended the need for amendments in the definition of dietary fiber (WHO, 2001). Moreover, 2 years later, the WHO representative proposed a new unique idea of dietary fiber that was completely different from the past definitions. They introduced the concept of intrinsic and added fiber to define the dietary fiber (WHO, 2003). At this stage, The National Academy of Science (NAS) also appeared in this debate and introduced the new concept of functional fiber to make it part of the definition of dietary fiber. Their definition proposed that functional fiber should be the part of total fiber in addition to traditional dietary fiber, whereas, traditional dietary fiber will include nondigestible plant carbohydrates and lignin. Moreover, the functional dietary fiber refers to nondigestible carbohydrates that have physiological health benefits in human beings (Tungland and Meyer, 2002). The Institute of Medicine (now called the National Academy of Medicine) published a similar kind of definition in defining dietary fiber. This definition is again a mix of old and new concepts, including nondigestible carbohydrates and lignin from plant sources along with functional fiber having some beneficial physiological health implications on the human body (Institute of Medicine, 2002).

In 2006 another development in defining dietary fiber appeared from the Codex Alimentarius Commission (CAC) Committee. The definition proposed by CCNFSDU tried to define dietary fiber on the basis of the degree of polymerization (DP) of carbohydrates. According to this definition, carbohydrates with at least a DP value of three and that are indigestible and unabsorable in the human small intestine may be included in the definition of dietary fiber (CAC, 2006). A bigger advantage of defining the dietary fiber in this way is to cover the enzymatically, chemically, and physically modified carbohydrate polymers in this definition. Furthermore, there will be more justification to include microbe-produced EPS and synthetic carbohydrate polymers in this definition of dietary fibers (CAC, 2006). One of the objections to this definition involved inclusion of low molecular weight oligosaccharides substances with a DP value of 3–9. To resolve this objection, it was decided that this issue may be left at the discretion of national authorities. Thus, there was a provision of a footnote in this definition that empowers national authorities to either consider it as a dietary fiber or not (CAC, 2009; Phillips and Cui, 2011).

A more refined version of this definition appeared in 2008, which defined dietary fibers as substances containing 10 or more monosaccharide units in the polysaccharide structure that are not broken down by the endogenous enzymes in the small intestine of humans. This may include food-edible carbohydrate polymers in their natural form; and natural carbohydrate polymers that are altered by physical, enzymatic, or chemical means and have physiological health benefits. This definition also includes synthetic carbohydrate polymers with demonstrable physiological health benefits (CAC, 2008, 2015).

Considering β-glucan to be a dietary fiber, it must fulfill the requirements as presented in the definition of dietary fiber. β-Glucan has a high DP, with some functional properties that have beneficial physiological health implications. The physical and chemical derivatives of β-glucan were also added in the definition of dietary fibers because these meet the requirements presented in the definition. Similar to the classification of dietary fibers, β-glucan can have soluble and insoluble fractions and have functional properties that can be utilized for development of the food products. A lot of health benefits are associated with its consumption, so it is regarded as a potential nutraceutical substance (Ahmad et al., 2012a,b).

Some other terms associated with dietary fiber are total dietary fiber, SDF, IDF, viscous dietary fibers, nonviscous dietary fibers, fermentable fibers, nonfermentable fibers, and functional fibers (Fig. 5.1).

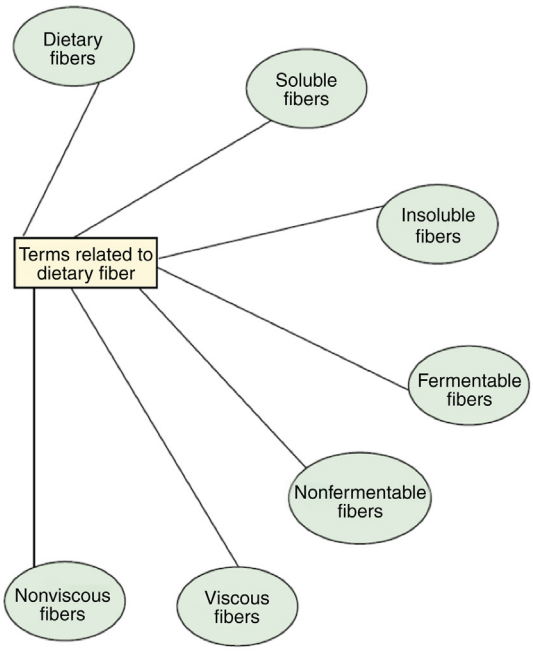

Figure 5.1: Terms Related to Dietary Fiber.

3 Dietary Fiber Classification

On the basis of function, dietary fibers are divided into various classes, including total dietary fiber, SDF, IDF, viscous dietary fibers, nonviscous dietary fibers, fermentable fibers, nonfermentable fibers, and functional fibers. Some of the terms in relation to dietary fibers are summarized in Fig. 5.1. Total dietary fiber refers to the sum of SDF and IDF. On the basis of solubility in water, the dietary fiber may further be classified as SDF and IDF. SDF absorb water in the gut, thus turning into a viscous gel-like structure. Important sources for SDF are oats, barley, beans, psyllium, and so forth. IDF adds bulk to the stool and helps food to pass quickly through the alimentary tract during digestion. Most of the time, these include cellulose, part of hemicellulose, and lignin fractions. Wheat bran, vegetables, beans, and whole grains are good sources for IDF. It is interesting to note that some part of hemicellulose is soluble and some part is considered insoluble and is dependent on the source. Viscous fiber refers to those forms of dietary fibers that absorb water inside the gut or outside the human body and offer resistance to flow in solution. It has greater physiological response in human beings, as it delays gastric emptying and slows down food passage in the intestine, thus taking more time to digest and absorb nutrients.

Viscous fibers have several applications in the food industry because it provides higher viscosity in beverage products and is used to prevent synersis in yogurt and other dairy products. Some of the examples for viscous dietary fibers are psyllium, β-glucan, pectin, guar gum, tara gum, glucomannans, and galactomannans. On medical grounds, viscous fibers are valuable to increase satiety, lower blood cholesterol levels, and control absorption of glucose in blood (Chutkan et al., 2012). On the other hand, nonviscous fibers, as the name indicates, do not impart viscosity but have several health implications. This may include dextrin, polydextrose, ructooligosaccharides, isomaltooligosaccharide, and some other low molecular weight carbohydrates. Another classification available in the scientific literature is fermentable and nonfermentable dietary fibers. Fermentable dietary fibers refer to dietary fibers that are unaffected by small intestine enzymes but have a capacity to undergo fermentation process by microorganisms residing in the large intestine. The function of this type of fibers is highly related to bowel regularity. As the fermentation process lowers the pH in the intestines, which increases the solubility of minerals, fermentable fibers are considered to be a great source for mineral absorption in the intestines (Macfarlane et al., 2006). Furthermore, several natural oligosaccharides (fermentable dietary fibers) help in colonization of intestinal flora within the intestinal tract of newborn babies. These microorganisms not only facilitate the digestion process, but also boost the immune system. So inclusion of prebiotic oligosaccharides (fermentable dietary fiber) in infant milk formula or weaning foods is recommended to improve the immune function in young children (Arslanoglu et al., 2012). Renowned fermentable dietary fibers include inulin fructans, xanthan gum, guar gum, oligofructose, and oligopolysaccharides. Nonfermentable carbohydrates do not possess the ability to be fermented in the large intestine.

β-Glucan from oats and barley is considered as a soluble fermentable fiber having the property to increase in viscosity in the small intestine and ferment in the large intestine. These β-glucans are fermented into short-chain fatty acids that are absorbed through the intestinal walls into portal blood. Most β-glucan consumed is fermented in the cecum and colon, producing short-chain fatty acids (Juvonen et al. 2009). Besides β-glucan, other polysaccharides that may undergo the fermentation process are pectin, resistant starches, gums, and inulin. These short-chain fatty acids have health-promoting effects on the body. Some of these effects include more insulin secretion; control of glycogen breakdown; lowering colonic pH that tends to improve mineral absorption; suppressing cholesterol synthesis in the liver; and stimulating production of T cells, leukocytes, and antibodies (El Khoury et al., 2012).

Another useful classification of dietary fibers is based on DP. Lower molecular weight carbohydrates with a DP value of 2–9 are called oligosaccharides, whereas higher molecular weight carbohydrates with DP values >10 are called polysaccharides (El Khoury et al., 2012). Oligosaccharides may exist as either maltodextrins that are basically α-glucans or they may exist as non-α-glucan. The α-glucans are the hydrolysis products from starches but non-α-glucan consists of raffinose and stachyose, verbascose, fructooligosaccharides, and galactooligosaccharides. The polysaccharide carbohydrates with a DP value >10 include either starchy substances or nonstarchy materials (cellulose, hemicelluloses, and pectin). In addition to these, they may also include gums, mucilages, and hydrocolloids (Roberfroid 2007).

4 Sources of Dietary Fiber and β-Glucan

With the diversity of research in dietary fiber, various sources are reported for dietary fibers. On the basis of water solubility of dietary fiber, these are classified as SDF or IDF. Some renowned sources of both types of these fibers are shown in Figs. 5.2 and 5.3. As indicated in the previous section, both types are beneficial for health. Some have viscous properties and have usage in the food industry, others have the ability to ferment in the large intestine and have health implications. Barley and oats are good sources for SDF, where it exists predominantly in the form of β-glucan within the endosperm and husk parts. High amounts of SDF (4%–12%) are reported from these two sources (Ahmad and Anjum, 2010). Apple pomace also consists of high fiber content (10.3%–16.4 %) in the form of SDF (Li et al., 2014). Brown rice is rich in IDF; it contains more than 14% of insoluble fiber (Thomas et al., 2015). Plant-based gum materials are also a good source of dietary fiber. Among different gum materials, guar gum from guara bean is a rich source of dietary fiber. Other sources among gums are xanthan gum, tara gum, and gum tragacanth. All of these gum materials contain 800–1000 g/kg total dietary fiber. Wheat bran and soybean sources also contain good amounts of dietary fibers ranging from 777–810 g/kg total dietary fiber (Ahmad et al., 2012a; Bourquin et al., 1996). Dried figs are also a good source of dietary

Figure 5.2: Selective Sources for Insoluble Dietary Fiber (IDF).

fiber with 4.6 g of dietary fiber per two figs. Resistant starch is another type of dietary fiber that resists digestion in the small intestine and is largely found in legumes. It is estimated that about 35% starch from legumes falls under this definition. Some of the resistant starch is also produced during the processing of native starch sources (Freeland-Graves and Nitzke, 2013). Some of the dietary fiber sources have an ability to ferment in the large intestine; soluble fibers (including β-glucan from guar gum, pectin, and gum Arabic) are highly suitable for fecal bacteria in large intestine, whereas, IDF from oat bran, corn bran, and wheat bran have less tendency to ferment in the large intestine. The presence of oligosaccharides, bioactive compounds, and antioxidants with the dietary fiber reinforces the prebiotic effect of dietary fiber (Bourquin et al., 1996). The source and chemistry of the dietary fiber may be used for the classification of dietary fiber. This will be an addition to previous classifications

Figure 5.3: Selective Sources for Soluble Dietary Fiber (SDF).

of SDF and IDF, and will be important to study the dietary fibers functional properties with reference to the source of dietary fiber (Giuntini and Menezes, 2011). On the basis of naturally occurring or synthetic carbohydrates polymers, the dietary fiber may be classified into three categories: (1) naturally occurring carbohydrate polymers that can be consumed as such as part of food; (2) carbohydrate materials that are extracted physically, chemically, or enzymatically from raw food and have some physiological health benefits; and (3) carbohydrate polymers that have been synthesized and have beneficial health effects as confirmed by scientific evidence by competent authorities (Phillips and Cui, 2011). It is customarily up to the consumer who usually consumes cereal grains, pulses, legumes, fruit, and vegetables in their daily diet to fulfill the requirement for dietary fiber. Thus, the first category among the aforementioned classification is the most popular one. However, as the nutraceutical industry is growing at a fast pace, the dietary fiber in the second category is more likely to increase at a faster pace. Food manufacturers may respond to higher consumer demands of dietary fiber by extracting the novel dietary fibers from respective sources and incorporating them in food products. A greater focus on the development of healthy nutraceutical food products enriched with dietary fiber having good taste and other marketable characteristics can attract a large number of consumers (McCleary, 2011).

Sometimes dietary fiber can be classified on the basis of the source in which it occurs naturally or the source from which it is derived. One of the important types of dietary fiber is β-glucan, which can be extracted from cereals, fungi, mushrooms, molds, bacteria, and other sources. Among cereal sources, barley and oats contain higher amounts of β-glucan fiber. Rye (*Secale cereale*) grains are also rich in β-glucan and other types of dietary fibers. Besides these, other plant sources, such as fresh apples, apple pomace, and tomato fibers, are also rich sources of β-glucan (Ahmad and Anjum, 2010; Ahmad et al., 2012a,b). Owing to higher consumer demands and effectiveness of β-glucan as a dietary fiber, several scientists extracted this valuable substance from its respective sources and marketed it with different trade names. For instance, NutrimXe is a commercial product of β-glucan extracted from barley, whereas Rice Trim is a β-glucan preparation extracted from rice (Inglett et al., 2004). Some other researchers also explored several other sources for extraction of β-glucan. However, these have not been exploited in the form of commercial products, but they still have a great potential to be converted into commercial products. These sources include: millet (*Panicum miliaceum*), corn/maize (*Zea mays*), beans, flax, canary seed (*Tropaeolum peregrinum*), lentil (*Lens culinaris*), peas, rice (*Oryza sativa*), spelt (*Triticum spelta*), spring wheat, and winter wheat (Ahmad et al., 2012a,b; Demirbas, 2005). Apart from cereal sources, mushrooms also contain reasonable amounts of β-glucan. The health benefits associated with consumption of β-glucan is dependent on source. Thus, cereal β-glucan from mushroom will provide different health response as compared to cereal β-glucan. These differences in health benefits are attributed to variable composition of cereal and mushroom β-glucan. Some yeast species also have a great potential for extraction of β-glucan. This may include: *Kluyveromyces marxianus*, *Debaryomyces hansenii*, *Kloeckera apiculata*, *Zygosaccharomyces bailii*, *Schizosaccharomyces*

pombe, and *Saccharomyces cerevisiae* (Nguyen et al., 1998). Some fungi also produce β-glucan polysaccharides in higher amounts. Silva et al. (2005) reported two fungi sources for the extraction of β-glucan. This production can be enhanced by using fructose and sucrose as carbon sources. Mushroom sclerotia was also explored as a source for extraction of β-glucan. Three mushroom sclerotia are notable for extraction of β-glucan: sclerotia from *Pleurotus tuberregium*, *Pleurotus eryngii*, and *Pleurotus sostreatoroseus*. A simple hot-water extraction process can be used for this extraction process (Ahmad et al., 2012b; Carbonero et al., 2006).

4.1 Dietary Fiber and β-Glucan From Cereal Sources

Cereals grains are perhaps the most used food items consumed for staple food and they are a great source of dietary fiber. These sources include rye, millet, oat, sorghum, corn, barley, and wheat. The consumption of dietary fiber from these cereal sources is associated with many health benefits. Western countries that are consuming less than the recommended amounts of dietary fiber are still consuming cereals to fulfill 50% requirement of daily intake of fibers, although they are using wheat and rice to fulfill their dietary fiber needs. However, barley and oats are richer sources of dietary fiber, including β-glucan (Ahmad and Anjum, 2010). All over the world the use of β-glucan from barley and oats is increasing at a high pace. Much attention is focusing on these sources to be used for extraction and as functional ingredients in foods. In addition to β-glucan, these two sources are also rich in antioxidants, phenolic substances, and tocotrienols, having numerous health implications. Another dietary fiber source that most of the cereals possess is arabinoxylan (Ahmad and Anjum 2010; Bacic and Stone, 1981). The aleurone layer of barley is the major part where arabinoxylan resides containing about 67% arabinoxylan as fraction of dietary fiber, whereas β-glucan resides within the starchy endosperm cell walls of barley (Fincher and Stone, 1986). Both of these are nonstarchy polysaccharides, dominant in barley and oat cereal sources (Bacic and Stone, 1981). Many researchers (Ahmad et al., 2012a,b; Henry, 1987; Nilsson et al., 1997) reported that β-glucan and SDF are higher in barley as compared to oat, whereas IDF dominates in wheat and rye, where these polysaccharides exist as hemicelluloses, pentosans, and arabinoxylans (Ahmad and Anjum, 2010).

4.2 Dietary Fiber From Yeast Sources

The β-glucan from a yeast source is quite different as compared to a cereal source in its chemistry and physiological health benefits. Several yeast species can be used for extraction of β-glucan. However, *S. cerevisiae* (brewer's yeast) has a greater potential for the extraction of β-glucan. The extracted β-glucan is composed of glucose units with β-(1→3) (1→6) linkages. Depending upon purity levels, small amounts of α-D-Mannan is also extracted along with this β-glucan (Auinger et al., 2013). The extraction from waste or spent brewer yeast may be a viable and cheap source for the extraction of yeast-based β-glucan. In this regard, the ultrasonic and enzymatic processes of extraction are optimized for greater yield of β-glucan. The combined use of enzymes and ultrasonic processes can reap higher

amounts of β-glucan from spent brewer's yeast. It is possible to achieve a recovery of 72% through this technique (Tam et al., 2013). The drying process increases the purity of yeast β-D-glucan and immunogenic activity. However, it does not significantly affect the yield of extracted β-D-glucan. Drying neither changes the spent brewer's yeast biomass carbohydrate content nor the chemical structure of purified β-D-glucan. However, drying increased purified β-D-glucan TNF-α induction activity in the murine macrophage model. We presume drying pretreatment enhances the purity of extracted β-D-glucan (Liepins et al., 2015).

4.3 Dietary Fiber From Bacterial Sources

Bacterial sources are considered as good sources of dietary fiber, including β-glucan. Several types of β-glucan can be extracted from this valuable source. The chemistry of the extracted β-glucan may vary and depends on specific bacterial species. Chemically, β-glucan may be a linear molecule comprising a repeating glucose unit held together by β (1→3) linkages or it may consist of glucose units having (1→3,1→6) glycosidic linkages. Sometimes these exist as cyclic structures having branching at 1→2 position to get a chemical structure of (1→3,1→2)-β-glucans. Both prokaryotes and eukaryotes have an ability to produce β-glucan dietary fiber. The linear β-glucan molecule from a bacterial source is often referred to as curdlan and possesses gelling and suitable rheological properties that can be used for many food product applications (McIntosh et al., 2005). Curdlan can be produced commercially through a fermentation process using a variety of bacterial species. Among these species, *Agrobacterium* sp., *Pseudomonas* sp., and *Bacillus* sp. have a greater potential for the production of curdlan. Recently, a new source for low molecular weight polysaccharide from *Pseudomonas* species from soil samples was identified as a potential source of curdlan and named as *Pseudomonas* sp. QL212. The low molecular weight property is important for its increased solubility (Yang et al., 2016). Another source of curdlan was discovered from Saudi Arabian soil samples and was identified as *Paenibacillu*s sp. NBR-10. This species produces good amounts of curdlan as EPS. Sophisticated machine analysis revealed the chemical nature of this curdlan product as having β-glucose units linked together with 1→3 glycosidic linkages (El-Sayed et al., 2016). Some of the bacterial members from the *Agrobacterium* genus possess high capacity to produce curdlan in the form of homopolysaccharide with a glycosidic linkage of (1→3)-β-glucans. This type of curdlan is devoid of branching and perhaps the most used bacteria for the scientific studies of curdlan. Among various strains from this group, *Agrobacterium* sp. ATCC 31749 has the highest potential to produce curdlan (Wu et al., 2016). Apart from curdlan-type β-glucan molecules, there are some identified microbial sources having the potential for the synthesis of dietary fiber as EPS. *Lactobacillus kefiranofaciens* ZW3 is a novel identified species having ability to produce EPS. This species was identified and isolated from Tibet keifer, and EPS isolated from this has all the properties of dietary fiber. This EPS holds greater water-holding and oil-absorbing properties, and its viscosity can be increased at acidic pH. When this EPS-producing strain (*L. kefiranofaciens* ZW3) was used with non-EPS-producing strains (*L. bulgaricus* and *Streptococcus*

thermophilus) in variable combinations, under these conditions dietary fiber in the form of EPS was synthesized having the composition of glucogalactan (Ahmed et al., 2013a,b).

4.4 Dietary Fiber From Fruit and Vegetables

Fruits and vegetables are good sources of dietary fiber, and fruit and vegetable waste may be a good option to recover dietary fiber. The apple and pear juice industries produce tons of waste material that contain valuable fiber sources and may be used as a valuable food ingredient (Morris, 1985). These materials mainly comprise cellulosic and hemicellulosic substances, along with lignin and pectin. If used in food products, they have great water-holding capacity. The extracted fibers from these sources may be incorporated in cereal-based products, baked items, granola bars, meatballs, dairy-based products, and confectionaries. The functional properties of spray-dried apple fiber were investigated by several researchers and were found to be at par with wheat and oat bran when used in bread, cookies, and muffins. On a weight basis, the dietary fiber content from waste apple pomace was higher than wheat or oat bran. Cellulose was the more dominant fraction in the apple fiber, followed by hemicellulose and lignin. This fiber holds a greater water-holding capacity (more than 9 times of its dry weight) due to the presence of hemicellulose and pectin (Chen et al., 1988). Similar results were obtained when dietary fiber from kiwi fruits and pears were tested from the waste-processing material collected from ultrafiltration plant of kiwi and pear puree processing facilities. Pear pomace and kiwi pomace contained dietary fiber of 43.9 and 25.8%, respectively. Pectin was the dominant material in these kinds of SDF sources (Martin-Cabrejas et al., 1995). In orange- and grapefruit juice–processing industries, peel and extracted pulp is the main waste material from which dietary fiber can be extracted in large amounts. The alcohol-insoluble materials from these wastes can be further fractionated as alkali- and acid-SDF that may be a great source of cellulosic-based dietary fiber, along with some uronic acid units (Ting and Rouseff, 1983). For pineapple peel, Larrauri et al. (1995) described a novel powdered-drink product that utilized dietary fiber from the peel portion. In addition to peel dietary fiber, this powdered drink also contained citric acid, sugars, foaming agent, color, and flavoring in the dry mix. The product was named as FIBRALAX, and had about 25.0% dietary fiber and 66.2% digestible carbohydrates. Another important source of dietary fiber is the peel and pulp waste from the extraction of peach juice. It is a rich source of dietary fiber containing about 31%–36% fiber material on dry weight basis. The greater portion is comprised of insoluble fiber, but soluble fiber content is low compared to cereal sources. Such fibrous material has high water-holding capacity and can be incorporated into bakery products, extruded products, and dietetic beverages (Grigelmo-Miguel and Martin-Belloso, 1997). In mangoes, by-product yield in a processing plant may range from 35%–60%. All of this material can serve as a source of dietary fiber. Almost equal amounts of SDF and IDF can be extracted. SDF from mangoes waste exhibits good shear-thinning properties and reduces starch digestibility when used in mashed potatoes. This is of major significance for type 2 diabetic patients where slow glucose diffusion is required (Gourgue et al., 1992). Grape pomace is another potential

source of dietary fiber having more than 77% of dietary fiber (on dry weight basis) in grape pomace from which grape juice has been extracted. The major portion of it comprises of SDF, hemicellulose, and pectin in small amounts (Valiente et al., 1995). The same amount of dietary fiber also exists in date flesh and seed. The coarsely milled fraction of dates contains about 71% dietary fiber that can be added to numerous food products. It is interesting to note that Saudi Mafrood date seed fiber, when incorporated into baking products, has the same organoleptic properties as the control bread product (Almana and Mahmoud, 1994).

5 β-Glucan as Dietary Fiber

β-Glucan is a nonstarch polysaccharide having the capacity to act as a dietary fiber and is found within cell walls of cereal kernels, bacteria, fungi, molds, mushrooms, and algae. Among cereals, barley and oat are rich sources for this type of dietary fiber where the major part of this dietary fiber resides within the endosperm, and the other may be concentrated within the aleurone layer. The naked or dehulled oat is contains higher amounts of β-glucan that may go up to 9%. Other cereals, such as rye, may contain β-glucan in the range of 1.3%–2.2% (Ahmad et al., 2012a; Hansen et al., 2003). Whole wheat is a less important source for this dietary fiber. Other cereals that may contain β-glucan include rice, millet, and maize, but in lesser amounts (Demirbas, 2005). The levels of β-glucan in these cereal crops are regulated by multiple genes that are interconnected by expression networks, thus effectively controlling the metabolism and biosynthesis of β-glucan in these cereal grains (Islamovic et al., 2013).

Whatever the source of β-glucans, it will mainly be comprised of repeating units of β-D-glucose to form a carbohydrate polysaccharide of variable chain length. Thus, it will have variable molecular weight, and based on the source and variability in molecular weight, its physiochemical properties differ significantly. In linear structures, the β-D-glucose molecules are linked together through 1→3 glycosidic linkages. These may sometimes have branching that may originate as 1→4 or 1→6 linkages depending upon the sources and is variable in cereals and molds. This variability in chemistry and structure is important in understanding its physiochemical properties, such as molecular mass, rheology, solubility, water-holding properties, viscosity, foaming capacity, branching structure, and gelation properties. The diversity based on aforementioned parameters is also responsible for diverse physiological effects in human beings and animals. Availability of diverse sources for β-glucans and its potential against numerous maladies encourages industrialists to take an interest in incorporating this valuable ingredient into food products for the development of nutraceutical food products. There are numerous low glycemic index (GI) foods that are available for diabetic patients, and these are produced through incorporation of β-glucan. Food researchers are striving hard to develop new functional foods with β-glucan fibers that will be of great help for diabetic, cardiovascular, and cancer patients and will act as prophylaxis against these diseases (Ahmad et al., 2010, 2012a; American Diabetes Association, 1999).

Like other dietary fibers, β-glucan might be extracted from diversified sources, including bacteria, fungi, algae, cereals, marine plants, and mushrooms. Extraction can be carried out using alkali media, acidic media, or using several enzymes. These extraction conditions can be applied as a sole technique or in combination with other techniques. Extracted material will be rich in β-glucan along with some protein, vitamin, starch, and minerals as impurities, which need to be removed during the purification process. Whatever the extraction techniques adopted for extraction of β-glucan, the extracted material always has beneficial nutraceutical characteristics. It follows that several health agencies, including the FDA and WHO, recommend the use of β-glucan in daily diet. These recommendations are the driving force for incorporation of β-glucan into several food products. Industry people exploit this valuable ingredient as a food additive, stabilizer, fat replacer, viscosity modifier, and thickener (Ahmad et al., 2008, 2010, 2012a)

β-Glucan as a dietary fiber is often recommended as a great nutraceutical ingredient. Several researchers have reported the potential health implications of β-glucan from various sources. These health implications of β-glucan not only depend on the source from which it is derived, but also on its chemical composition. For instance, oat β-glucan is good for controlling high levels of triglycerides and saturated fats and thus reduces the risk of coronary heart disease. This property is basically based on its β-(1→3) and (1→4) linkages. With this linkage, β-glucan from oat and barley is called a mixed-linkage β-glucan and has numerous functionalities that give it unique properties to act as a dietary fiber. The repeating units of glucose that are arranged in these glycosidic linkages exist either in cellotriosyl or cellotetrosyl units that are important for most of the physiochemical properties of β-glucan dietary fiber. β-Glucans derived from yeast and mushrooms are considered highly effective in strengthening the immune system. This property is based on its β-(1→3) and (1→6) glycosidic linkages. Bacterial β-glucans also have immunomodulatory effects and can be used as nutraceutical ingredients in foods and cosmetic products (Ahmad et al., 2012a,b). Owing to β-glucan's great health benefits, several authorities in the United States and other developed countries have already allowed health claims for β-glucan–containing foods. There is a consensus that consumption of 3 g/day oat or barley β-glucan can lower the blood cholesterol level by a value of 5%–8 %. These benefits of β-glucan have also been acknowledged by the FDA and the European Food Safety Authority. A large study that lasted for 6 years and consisted of data from more than 65,000 individuals revealed that dietary fiber, including β-glucan, is highly effective against development of type 2 diabetes. Previously, mushroom β-glucans were considered to effectively control the glycemic response. However, recent reports show a great potential for it in manufacturing of foods for diabetic patients (Brennan et al., 2013; Salmerón et al., 1997a,b). Whatever the source of β-glucan, it may provide beneficial effect through its high viscosity or gel formation properties and delay the absorption of certain nutrients, including glucose and other sugars, thereby slowly passing the glucose into the bloodstream and lessening the requirement of insulin entering into cells. The high viscosity and gelling power in barley and oat β-glucan is highly dependent on

molecular weight and cellotriosyl chemistry. Although barley and oat β-glucan have similar chemical structure, oat β-glucan has a greater capacity to form more viscous solutions. The phenomenon for this high viscous behavior is still not understood and requires more research to understand the gelation behavior of oat β-glucans and factors affecting this process. The in vivo viscosity property of β-glucan is an important phenomenon in the upper digestive tract, but little is known about its viscosity change behavior. However, it is evident that an increase in viscosity in the upper gut portion may lead to slow digestion and absorption and delay starch degradation. This may be due to the weak action of pancreatic amylase on starches. Some other factors, including nonstarch polysaccharides, might also be involved during this mechanism to define the physiological functionality of β-glucan well (Regand et al., 2011). Other documented short-term benefits of β-glucan include lowering of postprandial glycemia and insulinemia, and hypercholesterolemia. There is a need to explore long-term effects of β-glucan in humans for which little research has been conducted. Another way through which oat and barley β-glucan act in our bodies is through the fermentation process in the large intestine in humans. As a result of this fermentation process, short-chain fatty acids are generated, which may have a stimulating effect on the pancreas for insulin release and may alter glycogen breakdown. In this way, they play a vital role in glucose metabolism and help to combat against insulin resistance (Clark and Slavin, 2013). Some studies indicate that β-glucan can help in prevention or late onset of certain types of cancers. In this case, the mushroom-derived β-glucan is highly effective in decreasing the risk of developing certain forms of cancer. There are ethnobotanical references that some Chinese medicinal mushrooms used in Chinese folk medicines have a tendency to prevent onset of certain cancer types and these have been consumed for centuries in China. Similar cases have also been reported in Japan where the consumption of protein-bound polysaccharides (β-glucan) derived from selective mushrooms are being used for the treatment of cancer. These treatments are thought to increase the immune responses that fight against the disease rather than directly killing the cancer cells (Chan et al., 2009; Vannucci et al., 2013).

6 Analytical Procedures for Dietary Fiber

In the scientific literature, various researchers described different methods for the analysis of crude fiber, fractionation, acid detergent fiber (ADF), neutral detergent fiber (NDF), and enzymatic determination of dietary fiber. Crude fiber determination is perhaps the oldest one based on alkali and acid digestion. It is obvious that this method gives lower fiber values because it does not include most of the polysaccharides present in the plant cell wall that are undigested in the human intestine. Therefore, it has little value in nutritional studies. ADF and NDF is usually used for animal feed analysis and is based on refluxing the sample in acid with cetyl trimethyl ammonium bromide because this method determines most of the cellulose and lignin but does not focus too much on other cell wall polysaccharides. Presence of starches and hemicellulose is inadequately determined in this method. Due to

these limitations, there are very few applications in human foods. Sometimes, when ADF is used for human foods, the result can be reliable if the sample is defatted before analysis. However, ADF measures only a fraction of the cell wall polysaccharides that escapes the digestion process in the human intestinal tract (Hall and Mertens, 2012; Hassani, 1989; Montoya et al., 2016). However, using an NDF analytical method, the sample is reflexed with neutral detergent, such as sodium lauryl sulfate, EDTA, sodium borate, disodium hydrogen phosphate, or ethylene glycol. The disadvantage of this method is the inaccurate determination of SDF and it is not reliable for determining it from food sources (Dhingra et al., 2012). The Southgate method is effective enough to extract SDF and IDF along with lignin but the limitation with this method is the inefficient removal of starch from some food material. This fractionation method, introduced by Southgate (1969), was reliable enough for the estimation of dietary fiber as polysaccharides and lignin. This method fractionates the dietary fiber into polysaccharides and lignin. This method was further refined and introduced a new method to improve accuracy (Southgate, 1978). One of the major objection to this method is its dependency on a colorimeter for the determination of sugars. This kind of sugar determination is often misleading for different types of sugars in the sample, if the sample includes dietary fiber with complex sugars (Selvendran and Dupont, 1984). The method of Theander and Aman (1979) also provides a better way for the estimation of SDF and IDF, but the limitation of this method is its inefficient removal of cellulosic material. This method solved the problem of inefficient removal of starches as faced by the Southgate method. This was made possible by the use of a termamyl enzyme for the degradation and gelatinization of starches in the sample (Hassani, 1989; Theander and Aman, 1979). A greater change in the fiber method was introduced by Englyst et al. (1982), by adopting the GC method of analysis. This method improves the specificity, accuracy, and precision. However, as with other analytical techniques, this method also has some limitations, the greatest of which is the estimation of lignin that is calculated by difference. Most of these methods at that time were either focusing on the determination of IDF or total dietary fibers. There was little focus on soluble fraction of dietary fiber. Asp et al. (1983) describes the fractionation of SDF and IDF in the determination method. In their method, they used alcohol to precipitate the soluble fraction of the dietary fiber. At that time, the use of enzymes for the removal of undesirable parts of dietary fiber became the part of reliable determination of dietary fiber along with the precipitation that could be achieved either by alcohol or dialysis process. By gathering this information, Prosky et al. (1985) introduced the combination of enzymes in his determination protocol. This method made use of a starch-degrading enzyme (termamyl), a protein-digesting enzyme (protease), and amyloglucosidase, so it is a reliable combination of enzymatic gravimetric method for the determination of dietary fiber. One of the great successes in this method is the use of α-amylase that can withstand higher incubation temperature during dietary fiber determination. Still this method cannot quantify most of the resistant starches and indigestible oligosaccharides. The limitation of this method is that most of the AOAC

methods for determining TDF are also based on enzymatic–gravimetric method of determination. These methods are faster as compared to the Englyst method that is laborious and time consuming (Dhingra et al., 2012). The enzymatic gravimetric method is of prime importance where polysaccharide, lignin, and some resistant starches need to quantified; oligosaccharides are not determined efficiently by this method. This method determines total dietary fiber as a sum of soluble polysaccharide plus insoluble polysaccharides plus lignin. Recovered dietary fiber in this method consists of cellulosic material, hemicellulosic material, pectin, lignin, part of resistant starches, and some other nonstarch polysaccharides that are not listed here, whereas the enzymatic chemical method is suitable when nonstarch polysaccharides and uronic acid polymers, along with Klason lignin, are to be determined. The AOAC method number 45.4.11 explains this method of determination of dietary fiber well. In this method, soluble fiber is precipitated using alcohol after the removal of starch, and both soluble and insoluble fractions are hydrolyzed with sulfuric acid. GLC analysis is used to quantify neutral sugars, whereas colorimetric analysis is used for uronic acid determination. For the purpose of Klason, the lignin gravimetric method for quantification is used. This method has an advantage over the gravimetric method because it separately quantifies nondigestible oligosaccharides and resistant starch (McCleary and Monaghan, 2002). During the period 2006–09, researchers all over the world had several discussions on refining dietary fiber to an acceptable definition. During these discussions, the CAC was a major contributor. With these discussions, analytical methods based on a new definition were also a hot topic of discussion. The brainstorming debates were concluded in 2008–09, and experts agreed upon on a new definition. This definition has three main categories. First, it includes carbohydrates that are not digested and nonabsorbed in the small intestine; second and third categories describe extracted and synthetic carbohydrate polymers but these have to be recognized by appropriate authorities for physiological benefits. For the purpose of analytical procedure, the second and third categories were difficult to analyze (CAC, 2008; Mann and Cummings, 2009). A few years back, a new method for dietary fiber determination was reported by McCleary et al. (2010). This method is based on AOAC official method 985.29 and is valuable for determination of dietary fiber along with nondigestible oligosaccharides (Elleuch et al., 2011). For nondigestible oligosaccharides, some researchers explored chromatographic techniques. These methods have an application for pulses, beans, and legumes. Use of high-performance anion-exchange chromatography coupled with pulsed amperometric detection offers a reproducible method for such determinations (Bainy et al., 2008). For lower molecular weight nondigestible oligosaccharides having two to three monomers, these determinations are simpler, but as the number of monomeric units increases the differentiation becomes a difficult task. Therefore, for analytical purposes researchers often prefer to include those nondigestible carbohydrates in the definition of dietary fibers that have the least number of monomeric units. Such inclusions will broaden the list of dietary fiber–containing food products in different geographic regions (Westenbrink et al., 2013).

Most of the approved methods of dietary fiber neither exactly measure the nondigestible oligosaccharides nor the greater part of the resistant starches. McCleary (2007) proposed a better way for determining dietary fiber in food samples. He used an integrated approach for quantifying total dietary fiber that may include most of the resistant starches and indigestible oligosaccharides. This proposed method became the basis for the official AOAC 2009.01 method. The acceptance of this method for the determination of dietary fiber was worldwide because this method closely mimics the conditions that prevail in the human intestinal tract. Use of pancreatic α-amylase as present in the human intestinal tract, the use of amyloglucosidases as present in the human intestine, and maintenance of pH 6 at a temperature of 37°C were some suitable features of this method. However, one limitation of this protocol is the incubation time (16 h). Too long an incubation time does not match well to the human gut conditions. McCleary et al. (2010) proposed another method that measures the dietary fiber in accordance to CODEX definition of dietary fiber. The CODEX method consists of an enzymatic–gravimetric method and a liquid chromatographic method. The CODEX method was suitable for determining high and low molecular weight dietary fiber. The efficiency of this method is acknowledged worldwide because this protocol quantifies the whole range of dietary fiber components, including resistant starch (according to the requirement of the AOAC method 2002.02) and indigestible oligosaccharides (by use of liquid chromatography as per the requirement of the AOAC method 2001.03). The method was validated through an AOAC collaborative study in which 18 laboratories participated. The dietary fiber content of the eight test pairs ranged from 11.57% to 47.83%. Digestion of samples was carried out as per requirement of the AOAC method 2002.02. This was followed by the isolation of dietary fiber through enzymatic–gravimetric techniques in accordance with AOAC methods 985.29 and 991.43. This resulted in exact measurement of high molecular weight dietary fiber. The filtrate obtained during high molecular weight dietary fiber quantification was processed for determination of low molecular weight dietary fibers. The processing steps include concentration of filtrate, deionization, and final concentration, where, low molecular weight dietary fiber represents nondigestible oligosaccharides of a DP value of 3. In this method, total dietary fiber was calculated by adding values of high molecular weight dietary fiber and low molecular weight dietary fiber. This became the basis for the McCleary method (AOAC 2009.01). This method clearly and accurately determined the total, high and low molecular weight dietary fiber and closely mimics the human gut conditions. The only limitation with this method was the long incubation time. Therefore, this method was further refined by increasing the amount of enzyme used to shorten the incubation time. This provided an edifice for AOAC 2011.25 method for the determination of insoluble and SDF in food products (McCleary et al., 2010, 2013).

7 Health Benefits

Numerous health benefits for dietary fibers from variable sources are reported in scientific literature. To achieve the proper health benefits of dietary fibers and to prevent chronic disease or to avoid development of risk factors for several diseases, American Dietetic

Table 5.1: Adequate intake for dietary fiber at different ages.

Age (Years)	Adequate Intake (g/day)	
1–3	19	
4–8	25	
9–13	Male: 31	Female: 26
14–50	Male: 38	Female: 25
>50	Male: 30	Female: 21
Pregnant or lactating women	28–29	

Source: Institute of Medicine, 2002. Dietary Reference Intakes: Energy, Carbohydrates, Fibre, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids. Food and Nutrition Board, National Academies Press. Washington, DC.

Association recommends the consumption of dietary fibers from diversified sources. They recommend an amount of 14 g dietary fiber per 1000 kcal on a daily basis as dietary reference for intake. To avoid cardiovascular and related problem, it is advisable to consume at least 25 and 38 g/day of dietary fiber daily for adult women and adult men, respectively. The recommended intake of dietary fiber for different age groups for achieving proper health benefits is listed in Table 5.1. However, more research is required to recommend dietary fiber intake in the case of children and very old people. Developed and industrialized countries are consuming much lower amounts of dietary fibers on a daily basis. For instance, the intake of dietary fiber in the United States is limited to 15 g/day. SDF tend to absorb more water and provide bulk in the stomach and small intestine and have more satiety effect. These also have health implications in lowering body weight. There is sufficient evidence that the consumption of SDF from mushrooms and molds prevents or lowers cancerous growth. Owing to numerous health benefits, most of the consumers are now turning toward the use of food supplements rich in dietary fiber (Slavin, 2008; American Diabetes Association, 1999). Some people are of the view that the current idea of increased carbohydrates in diets of industrialized nations originated with the concept of low-fat diets, while protein in the daily diet remains unchanged. Among the numerous health benefits of dietary fiber, gut health is the most vital and important aspect. Some of these effects are exerted in the small intestine, and others are relevant to the large intestine, where it controls digestion, absorption, and the fermentation process (Schweizer and Edwards, 2013). The provision of indigestible material improves intestinal functions, favors the colonization of microflora, and increases fecal bulk. In the past, the health implications of dietary fiber were limited to indigestible plant cell walls comprising cellulose, pectin, lignin, and some other nonstarch polysaccharides. More recently, in addition to conventional cell walls some other substances, including resistant starches and nondigestible oligosaccharides, are also included in definition of dietary fiber. Starch is a digestible polysaccharide but not included in the definition of dietary fiber. However, it takes more time to digest as compared to smaller oligosaccharides. Thus, they have better characteristics for digestion and absorption in comparison to sugars and low molecular weight carbohydrates in reference to low GI (Miller, 1994). The relevance of GI with diabetes management and prevention is evident from scientific literature. Consumption

of high GI food is associated with secretion of insulin in higher amounts and also has an influence on insulin sensitivity, and these conditions are particularly important in diabetic patients. The number of diabetic patients is increasing at a high pace and it is estimated by the year 2030 the number of these patients may rise up to 552 million globally. This necessitates more specialized food products that may cater to the needs of such patients (International Diabetes Federation, 2011). Certain foods rich in dietary fiber, including cereals, fruits, vegetables, and dietary fiber supplements, may be required in higher amounts with the concept of modified GI required for that purpose. The consumption of such food products also lowers the incidence of C-reactive protein associated with onset of diabetes (Kantor et al., 2013). There is evidence for strong inverse relationship for diabetes and intake of total grains, whole grains, dietary fiber, cereal fiber, and dietary magnesium (Meyer et al., 2000).

8 Application in Foods

Nonstarch polysaccharides from cereal or microbial sources possess numerous functional and industrially important properties that lead the way for the development of food products. The same is true for β-glucan dietary fibers extracted from barley, oats, mushrooms, or microbial sources. These dietary fibers not only modify the nutritional properties of the food product, but also have a great influence on rheological, textural, gelling, and other aspects of products in which these are added as food ingredients. β-Glucan and soluble and insoluble parts of dietary fibers are equally important in food products. β-Glucan, SDF, hemicelluloses, and arabinoxylans have good water-holding properties; thus they are very effective in controlling rheology and viscosity of the liquid food products. In baking products, these are still effective as they lessen the staling process by controlling the starch retrogradation and recrystallization of amylose and amylopectin (Ahmad et al., 2012b, 2014; Wiege et al., 2015). Barley and oat can be used in the same way in food products or their dietary fibers can be extracted for utilization in the food products. These two cereals are rich in dietary fibers and they and β-glucan have numerous applications in the food industry. For barley, hullless barley varieties naturally containing more fiber content can be utilized in production of cakes, muffins, cookies, flakes, whole-wheat breads, and wholemeal flour. Some other food applications of barley and its dietary fiber include: ready-to-serve soup, breakfast cereals, rice puddings, porridge, sausages, and noodles. Some researchers also used barley flour and dietary fiber in flat breads, tortillas, and Turkish bread. Chemically leavened products also have a great prospect of using barley along with its dietary fibers where it can fully or partially replace conventional refined wheat flours. Such replacements are valuable in the production of biscuits, cakes, muffins, and pancakes. In the case of pasta products, complete replacement with dietary fiber–containing barley flour is not possible, but there is a possibility of replacing 20%–30% of wheat flour with barley flour to make an acceptable product. Some researchers reported the prospect of barley flour and β-glucan from barley to produce noodles. This incorporation of barley β-glucan will guarantee health benefits without compromising the

color, texture, and other physiochemical characteristics of the noodles (Ahmad et al., 2008; Hatcher et al., 2014; Wiege et al., 2015).

S. cerevisiae cell wall is a good source of dietary fiber and with β-D-glucan. It is used as such in many fermented food products or it may be used for production and extraction of β-glucan that can further be utilized in food products. The choice of isolation and fractionation of the yeast cell wall also influences the functional properties of extracted β-glucan molecules and in turn their usage into food products. The insoluble β-D-glucan fraction produced during the process can be used due to its high viscosity and brightness. The fractionation process also influences the structure of β-glucan and thermal properties as exhibited by differential scanning calorimetric technique. No matter which fractionation and isolation technique is used for the extraction of β-glucan, the extracted material possesses good nutritional and prebiotic properties to be used in the development of food products. In this study, researchers concluded that insoluble fraction has better swelling power, viscosity, and fat-binding characteristics. All of these properties showed a good potential of extracted β-glucan for industrial applications (Borchani et al., 2016). Yeast β-glucan along with hydroxyl methylcellulose and protein isolates can be used for the manufacturing of a gluten-free bread product using rice starch as the major ingredient. Sensory results indicated a great acceptability of this product. Researchers optimized these ingredients using response surface methodology and examined physiochemical parameters of this gluten-free product. These parameters, along with organoleptic properties, of the product seem to have a market potential as a new gluten-free product (Kittisuban et al., 2014). As an alternative to wheat flour, it is possible to develop some nutraceutical material from mushrooms (*Lentinus edodes*). This specialized material from mushrooms was rich in β-glucan and was used for the development of a powdered material that can act as a substitute for wheat flour. Such materials have an application for the production of baked goods and cakes having more dietary fiber and β-glucan content as compared to similar products made by natural wheat flours (Kim et al., 2011).

β-Glucan and other dietary fibers have a great acceptance in the food and nonfood industries due to their thickening, water-holding, emulsion-stabilizing, and gel-forming characteristics. There is a big market for pharmaceuticals and health food, and β-glucan has the potential to be incorporated as a vital ingredient for the development of these food products. Such foods may include β-glucan–containing sausages, beverages, cakes, snack foods, and many more. Some other industrial applications of β-glucan are in medicine, pharmaceuticals, cosmetics, veterinary usage, chemical industries, and feed mills (Ahmad et al., 2012b; Zhu et al., 2016). β-Glucan utilization and its properties were evaluated for the preparation of rusk with a special focus on flour particle size and hydrothermal treatments. If hydrothermal treatment is effective to inactivate the glucanase enzyme, it may preserve the molecular integrity of β-glucan. Thermal treatment during autoclaving was responsible for increased viscosity during the dough preparation step. A similar effect was observed for increased particle size on rheological properties of rusk dough. Higher particle size also reduces in vitro starch

degradation in rusk material (Lazaridou et al., 2014). Another application of β-glucan from oats was explored to develop a low-calorie milk-based product. Researchers in this case make use of the high molecular weight β-glucan from oats to achieve cholesterol-lowering properties. Several industrially important parameters, including rheological behavior, phase separation, and microstructure, were analyzed. Phase behavior was greatly influenced by β-glucan and the structures developed by β-glucan addition. Overall, β-glucan introduces a strong structure and texture by modifying the dairy matrices. β-Glucan also interacts well with milk protein casein and causes macroscopic phase separation even when incorporated at very low amounts. Usage of β-glucan in higher amounts facilitates the development of microstructures at the mixing stage. These microstructures impart suitable rheological properties to the dairy mixes (Sharafbafi et al., 2014). In another dairy product, that is, yogurt, the use of β-glucan along with pectin reduces the release of larger peptides during proteolysis process in in vitro digestive tract (Rinaldi et al., 2015). Ready-to-eat extruded snack products incorporate β-glucan in diabetic food or in the development of modified GI foods. A level of 10% β-glucan incorporation in the food product is sufficient to achieve a significant ($P < 0.05$) increase of dietary fiber in extruded products. This level is also appropriate to get required significant expansion and to reduce hardness in the extruded product for both barley and mushroom β-glucan. The addition of β-glucan from these sources also delays the rate of in vitro digestion and sugar release in comparison to control samples, causing lowering of glycemic response (Brennan et al., 2013). Some researchers showed the potential of barley β-glucan or fruit dietary fiber for the development of a nutraceutical beverage product. Incorporation of 3-g barley β-glucan provides a feeling of stomach fullness for a longer period of time as compared to control or other dietary fiber addition in beverage products. Ghrelin response was suppressed for both fruit-based dietary fiber and β-glucan–containing beverage samples (Lumaga et al., 2012).

9 Chemistry and Extraction Procedure

β-Glucan is a dietary fiber mostly present in cereal crops as a nonstarch homopolysaccharide. In cereals these are predominantly present either in cell walls or within the endosperm. In case of hullless barley and oat cereals, these reside within the endosperm (MacGregor and Fincher, 1993). A mixed composition of dietary fiber prevails within these cereal sources. Although dominated by β-glucan but to lesser extent arabinoxylans, minor protein, cellulosic material, and ferulic acid also exist within starch matrix. This makes extraction of dietary fiber and β-glucan a complex process. Different dietary fibers have different chemical compositions that affect their properties, as well as their health implications. A brief description about the chemical composition of selective dietary fiber is given in Table 5.2. Among cereals, oats and barley are considered as rich sources of β-glucan, but variation is evident in both cereals and is dependent on genetic differences of varieties. Oats contain β-glucan in the range of 3%–7%, whereas barley has slightly higher amounts of 3%–11% (Skendi et al., 2003; Wood and Beer, 1998). Researchers introduced a big range

Table 5.2: Chemistry of selected dietary fibers.

Dietary Fibers	Backbone Repeating Units	Backbone Linkages	Side Chain Origin, if Any	References
Cereal β-glucan	β-D-Glucose	β-(1→4) and β-(1→3)	—	Kodama et al. (2016)
Fungal β-glucan	β-D-Glucose	β-(1→3) and β-(1→6)	(1→6)	Asare (2015)
Bacterial β-glucan	β-D-Glucose	Sometimes β-(1→3) linear: sometimes β-(1→3) (1→6) linear; sometimes (1→3, 1→2) cyclic	Normally side chain absent but if it exists, it may have 1→2 origin	Łowicki et al. (2015)
Cellulose	β-D-Glucose	β-(1→4)	—	Zamora-Carreras et al. (2015)
Xylan hemicellulose	β-D-Xylose	β-(1→4)		Quéméner et al. (2015)
Arabinoxylans	β-D-Xylose	β-(1→4)	Arabinofuranosyl α-(1→3) linkage	Nandini and Salimath, 2002
Glucomannans	β-D-Mannose and β-D-glucose	β-(1→4)	Sometimes side chain exist with (1→3) or (1→6) linkage	Chen et al. (2016)
Galactomannans	β-D-Mannose	β-(1→4)	Galactose (1→6) linkages	Chen et al. (2016); Boual et al. (2015)
Pectin	Polygalacturonic acid	α-(1→4)	—	Marriott et al. (2016)
Oligofructose	D-Fructosyl-fructose	β-(2→1)	—	Goh and Klaenhammer (2015)
Inulin	D-Fructosyl-fructose	β-(2→1)	—	Goh and Klaenhammer (2015)
Xanthan gum	β-D-Glucose	β-(1→4)	Trisaccharide side chain consisting of mannose–glucuronic acid–mannose) Linked O-3 to every second glucose unit.	Bourquin et al. (1996)
Gum Arabic	β-D-Glucose	(1→3) (1→6)	β-D-Uronic acid (1→6) linkages	Sarika et al. (2015)

of extraction and purification techniques for extraction of β-glucan. This may include hot water extraction (Ahmad et al., 2009a,b), solvent extraction (Bhatty, 1993), enzymatic extraction (Ahmad et al., 2010), and alkali extraction (Wei et al., 2006). As was already mentioned, the variable composition of source makes extraction and purification procedure a complex task, so it requires special attention to capitalize on its yield and functional properties of extracted dietary fiber as β-glucan. Sometimes, when extraction is carried out from barley, proteins and parts of arabinoxylans are also extracted along with β-glucan. In this case, purified β-glucan content on a dry-weight basis hardly increased by 85%, because protein was the major impurity, and the extraction process requires specific designing so that it can be maximally removed. In the case of oats, mixed linked β-glucan is extracted along

with arabinoxylans, cellulose, protein, minor lipids, vitamins antioxidants, minerals, and some phenolic substances (Ahmad et al., 2012b; Panfili et al., 2003). During the extraction process, natural enzymes play a vital role for the release of β-glucan. The indigenous activity of proteases, endoxylanases, lipases, esterases, arabinofuranosidase, xyloacetylesterase, and feruloyl esterase are important to release the β-glucan from various sources. Faster release of glucan from their source can be achieved by using endoxylanase preparations and endo-β-glucanase. The latter released more than 90% of the glucan even when the hot-water extraction was carried out (Kanauchi and Bamforth, 2001). Two enzymes belonging to the esterases group also facilitate the extraction of β-glucan from various sources. One enzyme catalyzes the hydrolysis of acetyl groups of xylan, while the second enzyme tends to break the ferulic acid ester bonds related to arabinoxylan, rather than β-glucan. Although each of the aforementioned enzymes can be used as the sole enzyme in the extraction process, better results can be achieved if these enzymes are used in combination (Kanauchi and Bamforth, 2001). Skendi et al. (2003) adopted acidic media for the extraction and purification of β-glucan from Greek oats. This method of extraction was actually a hot-water extraction method that was modified by adopting acidic media. In another attempt for extracting β-glucan from oats using hot-water treatments, a new modification was introduced that used termamyl enzyme that can withstand harsh temperature conditions. To increase the overall recovery, the samples were defatted using petroleum ether, and proteinaceous impurities were removed using protease enzyme. In the end, β-glucan precipitation was achieved either by $CaSO_4$ or ethanol (Johansson et al., 2005). In a similar attempt to extract β-glucan from oats, the raw material was boiled in water to inactivate indigenous enzymes followed by refluxing with ethanol for removal of lipids and lipid-soluble impurities. To the defatted samples, again a hot-water treatment was applied at 96°C. Under these conditions, termamyl enzyme (starch-degrading enzyme) was used and incubated to ensure starch removal. For the removal of protein impurities, pancreatin enzymes were used. Finally, ethanol was added into the media to precipitate β-glucan gum material. Precipitated material was separated by refrigerated centrifugation process (Dongowski et al., 2005). A similar hot-water extraction process with or without the use of starch-degrading enzymes can be applied for the extraction of β-glucan from barley. If amylases or other starch-degrading enzymes are used during extraction, it will increase the recovery of β-glucan dietary fiber by lowering the starch content in β-glucan gum material. The presence of starches often tends to increase the viscosity of the extraction media when hot-water extraction is carried out due to gelatinization of starches at higher temperatures. Papageorgiou et al. (2005) selected lower temperature for a longer time to avoid viscosity increase due to starch gelatinization when they were extracting the β-glucan using the hot-water extraction process,. At later stages, starch impurities were hydrolyzed using heat stable α-amylases. For further clarification and to avoid haze formation, they made use of sodium azide. The material was mildly acidifying and kept overnight. Centrifugation was carried out to separate the liquid portion that was neutralized and again centrifugation was applied. Dialysis against distilled water was applied before final precipitation with ethanol.

Ahmad et al. (2010) compared the acidic, alkaline, and enzymatic extraction processes for the extraction of β-glucan gum material. Under the conditions used, the enzymatic extraction process appeared most promising in terms of higher yield and recovery and removal of most of the impurities. All methods showed good characterization data for viscosity, water-binding capacity, and whippability. The data on these parameters are good indications that extracted β-glucan from oat raw material by these methods can lead to several industrial applications. A brief comparison of acidic and alkaline extraction processes is outlined in Fig. 5.4.

Apart from cereal sources, there are possibilities that β-glucan may be extracted from bacterial, mushrooms, or yeast sources. This requires different extraction protocols as compared to extraction from cereal sources. Yeast cell walls are rich sources of β-glucan, and the alkaline extraction technique is one of the promising methods to achieve higher recoveries from these sources. For this purposes, extraction of β-glucan can be carried out in alkaline media using 1 M KOH at a temperature of 4°C and with continuous stirring for 20 h. A centrifugation process to separate the supernatant from solids follows this process. Alkali extracts were stored and the solids were again extracted for 2 h under alkaline conditions maintained by 1 M KOH. Several alkali extracts made by this method were pooled and precipitated using saturated ammonium sulfate. The precipitated β-glucan was further purified in a centrifugation process (Nguyen et al., 1998). Another attempt was made for the extraction of β-glucan from mycelia of *Penicillium chrysogenum*. Again, the alkaline extraction method is a feasible method for the extraction of β-glucan. In this method, freeze-dried powder of mycelia was stirred continuously for 2 h under alkaline conditions maintained by 1 M NaOH. The supernatant was obtained through the centrifugation process and then for protein removal. As the proteins are removed, the media was neutralized to facilitate the precipitation of dietary fiber β-glucan. After removal of proteins, the pH was adjusted to neutral for the precipitation of polysaccharide. The dietary fiber was further purified using an exhaustive dialysis process, ensuring the removal of most of the water-soluble impurities from extracted β-glucan (Wang et al., 2007).

10 Conclusions

Dietary fiber has been defined differently in various eras and the definition keeps on changing with time. The health benefits of dietary fiber are everlasting and not affected by changing definitions. These health benefits are dependent on the chemistry and source of dietary fiber, including β-glucan. Health benefits also lead to numerous industrial applications of dietary fiber. Most of the industrial applications are dependent on some method of extraction. More research is required to determine the adequate intakes of dietary fiber in children and old people. Exploring the new low-cost extraction techniques can lead to development of new nutraceutical products at a reasonable cost. Overall, dietary fibers and β-glucan have a greater potential to drive the nutraceutical industry in the 21st century where consumers believe in better health using natural ingredients from food.

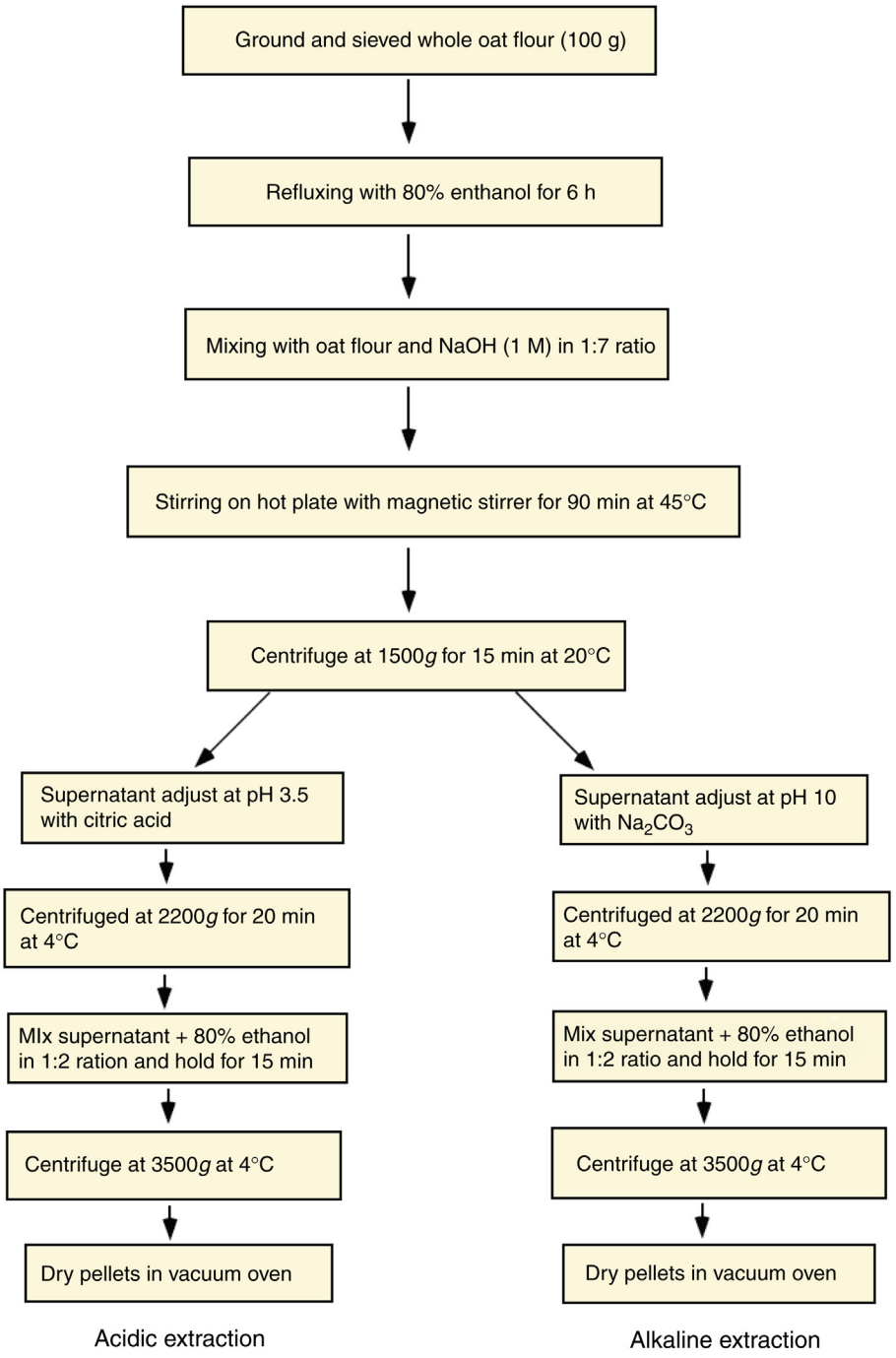

Figure 5.4: Extraction of β-Glucan From Oats.

From Ahmad, A., Anjum, F.M., Zahoor, T., Nawaz, H., Ahmed, Z., 2010. Extraction and characterization of β-D-glucan from oat for industrial utilization. Int. J. Biol. Macromol. 46 (3), 304–309.

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