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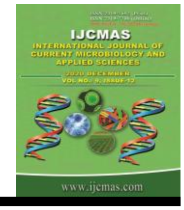


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# Beta Glucan: A Valuable Functional Ingredient in Foods

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**A B S T R A C T**

β-glucan is a valuable functional ingredient and various extraction techniques are available for its extraction. Choice of an appropriate extraction technique is important as it may affect the quality, structure, rheological properties, molecular weight, and other functional properties of the extracted β-glucan. These properties lead to the use of β-glucan in to various food systems and have important implications in human health. This review focuses on the extraction, synthesis, structure, molecular weight, and rheology of β-glucan. Furthermore, health implications and utilization of β-glucan in food products is also discussed.

## Introduction

Cereal grains produce a one seeded dry fruit called a caryopsis, (Ahmad *et al.*, 2016a) more commonly called kernel or grain. Nutritionally these grains are a good source of carbohydrates, lipids, proteins, vitamins, minerals, and other minor components (Evers and Millart, 2002). Beta glucan is one type of valuable dietary fiber present in cereal crops, especially in barley, oat, and some mushrooms. An updated definition of dietary fiber was presented by the AACC committee in the year 2001 (Ahmad *et al.*, 2015a) which reported that dietary fiber is the edible plant parts and analogous carbohydrates that offer some resistance to digestion and absorption in the human small intestine but partial or complete fermentation may occur in the large intestine (DeVries, 2001). The Codex Committee on Nutrition and Foods for Special Dietary Uses (CCNFSDU) illustrated that the current definition of dietary fiber should include both edible plant and animal material. However, most of the recent literature supported that the dietary fiber originate from plants. It was recommended by this Committee that the definition of dietary fiber should be amended to the current definition (WHO, 2001). The WHO representative offered a new concept of dietary fiber that introduces the idea of intrinsic and added fiber (WHO, 2003). The National Academy of Science proposed that total fiber is the sum of dietary fiber and functional fiber. Whereas, dietary fiber is a complex of non digestible carbohydrates (Ahmad *et al.,* 2015a) and lignin associated with plants, functional fiber is actually the type of non digestible carbohydrates having ben eficial physiological effects in humans (Ahmad *et al.,* 2015a; Tungland and Meyer, 2002).

Most of the definitions of dietary fiber were based on the physiological characteristics of non-digestion and non- absorption in the small intestine, together with some desirable health benefits. A latest and comprehensive definition of dietary fiber was proposed by CCNFSDU and by the Codex Alimentarius Commission (CAC, 2006). This definition declares that dietary fiber are carbohydrate polymers with at least a degree of polymerization of about three, and these are deprived of the ability to digest or be absorbed in the small intestine. According to this definition, naturally occurring edible carbohydrate polymers in food, physically, chemically, and enzymatically altered carbohydrate polymers are included in the group of dietary fiber. Furthermore, synthetic carbohydrate polymers were also covered by this definition (CAC, 2006). *β*-glucan is the principal fiber present in barley and oat. Although barley is an excellent source of *β*-glucan, yet on a world wide basis, a limited amount of the barley is also used as a source of *β*-glucan in various foods for human consumption but the major quantities of barley are used for animal feed (FAO, 2001). Owing to its importance the Food and Drug Administration (FDA) (Ahmad *et al.,* 2015a) allowed its use in food products and made it obligatory for labeling requirement to acquire health claim. It was also recommended that a diet high in soluble fiber from whole oats (oat bran, oatmeal, and oat flour) should be used to reduce the risk of heart disease (FDA, 1996). In its proposal FDA evaluated several studies for the consumption of oat products, for example, muffins, breads, shakes, and entrees. On the basis of these studies, a daily dose of at least 3 g of *β*-glucan from oats was recommended to achieve (Ahmad *et al.,* 2015a).

### β-glucan synthesis,

The enzymes endoglycosynthases help in synthesis of *β*- glucan molecules through catalyzation of reactions that in turn catalyze the self-condensation of sugar donors for the in vitro synthesis of a regular polysaccharide. The specificity of the enzyme allowed the polymerization of *α*-laminaribiosyl flu- oride via the formation of (1 4)-*β*-linkages to yield a new linear crystalline (1 3) (1 4)-*β*-D-glucan with a repeating 4-glucose and 3-glucose units (Ahmad *et al.,* 2015a); Magda *et al.,* 2004 Ahmad *et al.,* 2010). However, the mechanism may vary from species to species. Calcium promoted *β*-glucan synthase activity and promotion was also ob- served at free calcium concentrations (Paliyath and Poovaiah, 1988). Endo- *β* -(1 3) (1 4)-glucanase is a thermo-stable enzyme and develops during the germination of barley; this is the major enzyme associated with degradation of the *β*-glucan molecule after synthesis of *β*-glucan thereby controlling (Ahmad *et al.,* 2014c) the length and the molecular weight of *β*-glucan in cereal crops (Hrmova *et al.,* 1997). While in microorganisms (*in vivo*) a different situation exists, the structure of *β*-glucan is engineered under strict control of genes. To understand this structural phenomenon, two genes, KRE6 and SKN1 of *Sacchromyces cerevisiae*, were characterized. The characterization of these gene products broadens previous knowledge about genetic studies on their role in (1→6)-*β*–glucan biosynthesis (Roemer and Bussey, 1991).

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## Structure of β-glucan

*β*-glucan is the predominant non-starch polysaccahride of cell walls in cereal grains such as barley and oats (Buckeridge *et al.*, 2004;Wood, 1993; Izydorczyk *et al.*,2003). Structurally, cereal grains consist of long linear chains of glucose having *β*-(1→3) and *β*-(1→4)-linkages but these linkages are not arranged in a random and repeating fashion (Staudte, *et al.*, 1983; Ayhan, 2005). However, *β* -glucan from baker's yeast has a different type of linkage; it consists of *β* -(1→3) as well as (1→6) linkages (Gardiner, 2004). In cereals, *β*-glucan (1→4)- linkages occur in groups of two to four while (1 3)-linkages occur singly. This leads to a structure that is dominated by *β*- (1→3)-linked cellotriosyl and cellotetraosyl units (Woodward, *et al.*, 1983; Wood *et al.*, 1994; Wood, 2001). The rest of the structure consists of longer blocks of 4- 15 (14)-linked *β* -D- glucopyranosyl units (Wood *et al.*, 1994). The structure of *β*-glucan resembles that of cellulose, the only difference being that the *β*-(1→3)- linkages establish a twist in the chain. This twist phenomenon gives stability to *β*-glucan and lessens its affinity to form aggregates, thus the solubility of *β*-glucan is greatly affected by such a trend. A lot of investigations are still required to determine the rationale of *β*-glucan solubility and its inter- action with these linkages. However, some previous research predicts that longer sequences of (1→4)-linkages give less soluble *β*-glucans because of close intermolecular associations (Woodward *et al.*, 1983). However, Izawa *et al.,* (1993) were of the view that *β*-(1→4)-linkages had an insignificant influence on solubility as compared to that of long blocks of contiguous cellotriosyl residues. More recent data also holds up this assumption about structural regularity and gives an idea about how a high level of *β* (13) linked cellotriosyl units reduces solubility and increases the tend encytogel (Bohme and Kulicke, 1999; Cui and Wood, 2000). On average, two or three (1→4)-linked units exist and these are separated by a single (1→3)–linkage in a molecule. However, there is still a chance of longer units linked through (1→4)-linkages (Cui, *et al.,* 2000; MacGregor and Rattan, 1993). Like *β*-glucan, the arabinoxylans also have a backbone of (1 4)-linked *β* -D-xylopyranosyl units. Some of these may substitute at position 2 and/or 3 with a L-barley kernel it may present in the amounts of 3–11% (Hanand Schwarz, 1996; Jadhav *et al.*, 1998; Lehtonen and Aikasalo, 1987). The action of lichenase release, the main structural repeating units of *β*-D-glucans, as 3-*O*- *β*-D-cellobiosyl- Dglucose (trisaccharide unit) and 3-*O*-*β*-D-cellotriosyl-D- glucose (tetrasaccharide unit). The property of water solubility is attributed to the introduction of (1→3)-linkages in a cellulosic chain (Irakli *et al.,* 2004). The degree of branching is negatively correlated with a rabinoxylans (AX) and, similar negative cor- relation found between *β*-glucan and arabinoxylan contents; whereas, a strong positive correlation also exists between *β*- glucan and the amount of soluble non-starch polysaccharides (NSP) and protein contents was reported by Holtekjølen *et al*., (2006). Higher amounts of *β*-glucan have also been reported in waxy and the high amylose genotypes as compared to the normal genotypes (Anker-Nilsenn *et al.,* 2006).

## Extraction of β–glucan

A range of extraction and purification techniques are available for extraction of *β*-glucan (Ahmad *et al.,* 2015a). This may include hot water extraction (Smiderle *et al.*, 2006; Ahmad *et al.*, 2009), solvent extraction (Bhatty, 1993), enzymatic extraction (Irakli *et al.*, 2004; Ahmad *et al.*, 2010), and alkali extraction (Wei *et al*., 2006).

Indigenous enzymes may affect the recovery and properties of the extracted *β*-glucan. The major indigenous enzyme re- sponsible for hydrolyzing the *β*-glucan component in cereal is an endo- *β* - (1→3) (1→4) -glucanase, which develops during the germination of cereal crops (Hrmova *et al.*, 1997). Several other enzymes such a send o-xylanases, a rabinofuranosidase, xy- loacetylesterase, and feruloyl esterase are also involved in the release of *β*-glucan from various sources. The relatively faster release of glucan was reported by two endo-xylanase preparations, although the most extensive release of glucan was obseved by an endo- *β*-glucanase. The latter released 90% of the glu- can above which was extracted by water alone (Kanauchil and Bamforth, 2001). Furthermore, two esterases were capable of extracting glucan to a more limited extent, one of them hy- drolyzing acetyl groups associated with xylan, the other breaking ferulic acid ester bonds. The latter are associated more with a rabinoxylan rather than *β*-glucan (Ahluwalia and Fry, 1986). However, this would not confound the argument that hydrolysis of a rabinoxylans enables the solubilization of *β*-glucan. These enzymes can be used alone but better results were observed when these enzymes were used in combination at various levels (Kanauchil and Bamforth, 2001). During the extraction process an appreciable amount of a rabinoxylan is also extracted along with *β*-glucan. The presence of a rabinoxylan may con- tribute hindrances in filtration, extraction, and add have during the brewing process (Jadhav *et al.,* 1998; Mac Gregor and Rattan, 1993). These polysaccharides, if not extracted from animal feed, may pose some problems in such feed. The major draw back reported in animal feed is that it reduces the nutritive value of the feed. Other problems associated with these substances are sticky feces in poultry birds (Jadhav *et al.,* 1998; MacGregor and Rattan, 1993; Svihus *et al.*, 1995 (Ahmad, 2013a). Various extraction and purification techniques used for the extraction of *β*-glucan from the irrespective sources and the salient features of the extracted product are reviewed in Table 1.

## Molecular Weight of β-Glucan

Size exclusion chromatography presents a better way to determine the molecular weight and size (radius of gyration) of *β*-glucan and like polysaccharides (Lazaridou *et al.,* 2003). This technique is used in combination with various detectors such as refractive index detection (HPSEC-RI), multi-angle laser light scattering (MALLS), or with right angle light scattering com- bined with or without a viscosity (HPSEC-RI-RALLS-Visc) detector (Wei et al., 2006;Irakli etal., 2004). (Ahmad *et al.,* 2014d) These detectors may be used alone or in combination with each other. Researchers had also used light scattering techniques to determine molecular weights and mean square radius without employing reference standards (Wyatt, 1993). Some researchers have preferred the use of refractive index detector to determine the molecular weight (Jackson and Barth, 1995). Light scattering from multiple angles (MALLS) is another option that can be used to determine the average molecular weight. RI-Visc measures the intrinsic viscosity, and this is used in situations where the concentration of the test material is low (White, 1999). On the other hand, SEC-RI-MALLS use is confined for the average molecular weight. In size exclusion chromatography, it is assumed that each slice of a chromate gram contains molecules of a very narrow molecular weight distribution (Irakli *et al.,* 2004). Polysaccharides in cell walls consist of varying chain length and molecular weight. In such molecules the polydispersity can be calculated from the ratio of average molecular size to number average molecular weight. The average molecular weight is in- fluenced by the presence of size of the larger molecules, while the number of the average molecular weight is strongly influenced by the presence of small molecules. For a monodisperse polymer, the average molecular weight equals number average molecular weight giving a polydispersity of 1, all molecules thus having identical molecular weights (Cuiand Wood, 2000; Wei *et al.,* 2006). The calcoflour method is another procedure used to determine molecular weight of *β*-glucan. This process works on specific binding of Calcofluorto polysaccharide thus forming a glucan-Calcofluor complex that results in increased influorescence intensity and can be detected by a fluorescence detector (Trogh, *et al.*, 2004; Wood, 1980). Such binding results in an increase influorescence intensity that is proportional to the concentration of *β*-glucan in solutions. This technique was initially employed to quantify *β*-glucan (Wood and Weisz, 1984; Mekis *et al.,* 1987; Jørgensen, 1988) but today this technique along with size-exclusion chromatography (SEC) is used for molecular weight determination of *β*-glucan.Table2illustrates a brief review of various techniques used for molecular weight.

## Glucan-Binding Protein

The glucan-binding proteins (GBPs) are a heterogeneous group of proteins with variations in size, glucan-binding do- main, glucan binding affinity, distribution and most importantly, function. These proteins are grouped together on the basis of their glucan-binding properties (Banas and Vickerman, 2003). These are surface proteins and bind with the surface receptor after pattern recognition (Pauchet *et al.,* 2009) and the molecular weight for this *β*-glucan-receptor protein complex is approxi- mately 240k Da and it contains another important 75kDa protein species form a king strong complex (Mithofer *et al.*, 1996; Frey *et al.*, 1993). This 75-kDa protein was isolated and characterized as a high-affinity binding protein (Umemoto *et al.,* 1997; Mithofer *et al.*, 1996). Some of the enzymes are also associated with glucan-binding proteins. These enzymes catalyze the synthesis of the glucans. Furthermore, these enzymes also hydrolyze the glucans molecules along with starch and cellulose, which ultimately act as substrates for microbial growth (Warren, 1996). Some of the *β*-glucan-binding protein (GBP) has a capacity to hydrolyze *β*- (13) linkages in *β*-glucan (Fliegmann *et al.,* 2004). These glucan binding proteins play a major role during various processes such as dextranase inhibition, dextran- dependent aggregation, plaque cohesion (Banas and Vickerman, 2003), pathogen defense, metabolism, polysaccharide biosynthesis, and virulence (Guillen *et al.,* 2010). Recent studies indicated evidence that glucan-binding proteins amend virulence and sometime play a protective role by acting as immunogens in animal models (Ahmad *et al.*, 2013d; Banas and Vickerman, 2003). The *β*-glucan binding protein (GBP) extracted from soybean (*Glycine max* L.) perform two major roles. First, it acts as are captor complex within the plasma membrane upon the binding and acts as mi- crobial cell wall elicit or and triggers the cascade of reaction that resulted in activation of defense responses. The second important function of these GBP is to hydrolyze *β* - (1 3) -glucans that are present in the cell walls of pathogens (Fliegmann *et al.*, 2005).

## Rheological properties of β-glucan

The viscosity properties of *β*-glucan and other polysaccharides depend upon concentration of dietary fiber, their solubility, and molecular weight (MW) (AACC, 2001; Wood *et al.*, 1991; 2000). There are numerous factors that affect viscosities in products with added *β*-glucan. According to Aastrup (1979) changes in viscosity of barley flours lurries originate due to the presence of endogenous enzymes. Two endogenous *β*-(13) (1 4)-D-glucan 4-glucanohydrolase isoenzymes are responsible for the degradation of barley *β*-glucans (Woodward *et al.*, 1983). The major enzyme involved in hydrolyzing the *β*-glucan component of barley is an endo-*β* - (1 4) - glucanase, which develops during the germination of barley (Hrmova *et al.*, 1997). *β*-glucanases in cereals became in activated by a combination of heat (90◦C) and ethanol treatments for two hours and this had a pronounced stabilizing effect on the viscosity. A previous study has shown that heat treatment also has a capability of stabilizing the viscosity profile of flour slurries (Izydorczyk *et al.*, 2000). According to Wei *et al.*, (2006) the melting temperature of wheat *β*-D-glucan gels increased with the increase of molecular weight. Initially, viscosities of the *β*-glucan containing solutions tend to increase due to initial solubilization of the *β*-glucans, but no detectable decline has been observed there after. Addition of low purity *β*-glucan to the medium molecular weight starch significantly increases the viscosity of solution when determined at low shear rates (Faraj *et al.*, 2006). Fluid dynamic parame-ters also influence the flow, diffusion, or transport behavior of *β*-glucan during digestion in the small intestine, but the influence of the viscous behavior is limited. The rheological behavior of *β*-glucan was studied in the past by using oscillatory and rheological measurement. The predominant viscous behavior was explained on the basis of storage and loss moduli Gr and Grr of *β*-glucan preparations from extruded meal and bran that tends to increase continuously with increasing frequency (Dongowski *et al.*,



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2005). In freshly prepared barley *β*-glucan solutions, attraction forces between molecules are less strong but after an induction period some *β*-glucan solutions/dispersions may begin to adopt gel-like behavior (Bohme and Kulicke, 1999). She arthinning behavior of cereal *β*-glucans was also exhibited at low concentration, but at higher concentration they tend to form gels and their gelling properties are influenced by molecular weights and molecular structure (Cui, 2001; Lazaridou *et al.,* 2003; 2004; Lazaridou and Biliaderis, 2004). Higher molecular weight (2.39 105) *β*-glucan gel did not show any tendency to gel even after 200hours storage. On the other hand, short chain molecules with low molecular weight show higher mobility and these short chains with low molecular weight *β*-glucan structures diffuse more readily, and hence have a greater possibility of forming junctions with neighboring chains (Doublier and Wood, 1995). This evidence indicates that there is an inverse relationship between gelation time and molecular weight of the polysaccharide (Lazaridou *et al.,* 2003; Vaikousi *et al.,* 2004). Viscosity properties are also influenced by tri/tetra ratios, cellulose-like fragments, molecular weight distribution, and molecular size of cereal *β*-glucan. Furthermore, they have a capacity to alter some other physiological responses when they are intended to be used in cereal based products (Izydorczyk and Biliaderis, 2000; Vaikousi *et al.,* 2004).

## Health implication of β-glucan

A large number of studies indicated the effectiveness of *β*- glucan against various diseases and disorders, and several applications reported in previous scientific work are the tendency to reduce onset of colorectal cancer (Dongowski *et al.,* 2002), increased stool bulk and provide assistance against constipation (Odes *et al.,* 1993; Valle-Jones, 1985), reduction in glycemic index (Cavallero *et al.,* 2002; Jenkins *et al.,* 2002; Granfeldt *et al.,* 2008), flattening of the postprandial blood glucose levels and insulin rises (Hallfrisch *et al.,* 2003; Li *et al.,* 2003; Jenkins *et al.,* 2002), prevention of insulin resistance (Brennan and Cleary, 2007; Hlebowicz *et al.,* 2008), reduction in serum cholesterol levels (Delaney *et al.,* 2003; Kang, *et al.,* 2003; Kerckhoffs *et al.,* 2003; Li *et al.,* 2003; Yang *et al.,* 2003; Smithetal., 2004), prevention of coronary heart disease (Jinshui *et al.,* 2002), production of short chain fatty acids (Wisker *et al.,* 2000), prevention of hepatic damage by reducing taxol induced hepatic damage (Ahmad *et al.,* 2015b) Karaduman *et al.,* 2010), and promotion of the growth of beneficial gut microflora (Crittenden *et al.,* 2002; Tungland, 2003).

Viscous fibers are responsible for beneficial physiological responses in human, animal, and animal-alternative *in vitro* models (Cheryl *et al.,* 2006). These responses are altered primarily by *β*-glucan, but a rabinoxyl an may also influence these changes since both types of fiber have a tendency to increase viscosity in solutions (Newman and Newman, 1992). There is evidence indicating that *β*-glucan and other dietary fibers have protective roles to play in preventing or delaying the onset of chronicdis- eases and disorders such as coronary heart disease (Liu *et al.,* 2000; Truswell, 2002), diabetes mellitus, cancer, and colondys function (Meyer *et al.,* 2000; Sudha *et al.,* 2007). Tungland and Meyer (2003) also reviewed a range of dietary fiber including *β*-glucan with reference to beneficial physiological influences that they exert on the human body. To achieve these physiological responses 3 g soluble fiber consumption daily may lower the total cholesterol by 0.41 mmolL−1 in hypercholesterolemic persons and 0.13 mmolL−1 in normocholesterolemic persons (Kerckhoffs *et al.,* 2003). Similarly, Behall *et al.,* (1997) reported that ingestion of 2.1g of *β*-glucanona daily basis reduces total cholesterol by 9.5%, where as some findings by some researchers (Jenkins *et al.,* 2002) indicated that 4 units decline in glycemic index can be achieved by taking 1g of *β*-glucan per 50g of carbohydrates. FDA has also recommended a daily consumption of 3 g *β*-glucan to achieve such health benefits (FDA, 1997). In a comparison study to evaluate the effect of oat bran and oat meal (same quantity) on reduction of LDL-cholesterol, oat bran was found to have a greater capability over oat meal to reduce LDL-cholesterol levels (Davidson *et al.*, 1991). As concerned with source of *β*-glucan, barley *β*-glucan was more effective in the regulation of glucose and insulin responses compared too at *β*-glucan (Hallfrisch and Behall, 2000; Yokoyama *et al.,* 1997; Hallfrisch *et al.,* 2003; Granfeldt *et al.,* 2008). Regarding the cholesterol lowering mechanism and binding of bile acid, it was noticed that *β*-glucan containing extrudates from oat have an ability to bind bile acid and to replenish the deficiency of bile acid, more cholesterol from the body is consumed for the synthesis of bile acid thus lowering the serum cholesterol level in the body (Drzikova *et al.*, 2005). Higher bile acid binding capacity in oat *β*-glucan can be achieved by amination (Liu *et al.,* 2010) and oxidation (Park *et al.*, 2009) thus help in the removal of more cholesterol due to the introduction of cat ionic groups into the *β*-glucan molecules (Shin *et al.*, 2005;Liu *et al.,* 2010).

Apart from cereal grains such as barley, oats, rye, certain fungi containing *β*-D-glucan have a capacity to reduce total blood (Ahmad *et al.*, 2013 c) cholesterol level with in the body (Genc *et al.,* 2001; Ozdemir and Genc, 2001). Oat extract diets are considered to lower the total and LDL cholesterol levels, and a significant difference with respect to lowering of cholesterol was also observed within both high oat and low oat containing diets. This difference was attributed due to difference in *β*-glucan contents in the diets (Behall *et al.*, 1997).

Consumption of a diet high in barley *β*-glucan has been shown to prevent insulin resistance and can be used for diabetic patients (Ostman *et al.,* 2006; Brennan and Cleary, 2007; Hlebowicz *et al.*, 2008). The beta glucan containing diet promoted hepatic insulin signaling by decreasing serine phosphorylation of insulin receptor (Choi *et al.*, 2010). In are cent study, Beck *et al.*, (2009) observed decrease in insulin response and increased post prandial cholecystokinin levels after ingestion of *β*-glucan in over weight human subjects. Gran field total. (2008) suggested intake of 4 goat *β*-glucans to achieve significant decrease in glucose and insulin responses in healthy subjects thus favoring the diabetic patients. Several researchers advocated the need for reevaluation of the quantity, the food vectors, and the tolerability of *β*-glucan products to improve the metabolic profile of type 2 diabetic subjects in the long term (Cugnet-Anceau *et al.*, 2010).

## Application of β-glucans in food products

Apart from health and nutritional benefits (Malkkiand Virtanen, 2001), *β*-glucan also has various suitable functional properties such as thickening, stabilizing, emulsification, and gelation. These properties determine the suitability of *β*-glucan to be incorporated in soups, sauces, beverages, and in other food products (Dawkins and Nnanna, 1995;Burkus and Temelli, 2000). Barley *β*-glucan is particularly well suited for such applications, being capable of imparting a smooth mouth feel to beverage products, and also makes the beverage an excellent source of soluble dietary fiber. Its properties enable it to be incorporated alternatively in traditional beverage thickeners as replacement forgum Arabic, alginates, pectin, xanthangum, and arboxymethyl-cellulose (Giese, 1992).

**Table.1** Avena species – genome constitution and chromosome number

| Classification | Chromosome no. | Genome constitution |
|---|---|---|
| Section Avenotrichon | | |
| *A.macrostachya* | 4x=28 | |
| *Section ventricosa* | | |
| *A.clauda* | 2x=14 | $C_PC_P$ |
| *A.eriantha* | 2x=14 | $C_PC_P$ |
| *A.ventricosa* | 2x=14 | $C_vC_v$ |
| *Section Agraria* | | |
| *A.brevis* | 2x=14 | AA |
| *A. Hispanica* | 2x=14 | AA |
| *A. nuda* | 2x=14 | AA |
| *A. strygosa* | 2x=14 | AsAs |
| Section Tenaicarpa | | |
| *A. agadiriana* | | |
| *A. atlantica* | 2x=14 | AsAs |
| *A. barbata* | 4x=28 | AABB |
| *A. canariensis* | 2x=14 | AcAc |
| *A.damascena* | 2x=14 | AdAd |
| *A. hirtula* | 2x=14 | AsAs |
| *A.longiglumis* | 2x=14 | AiAi |
| *A.lusitanica* | 2x=14 | AA |
| *A.matritensis* | 2x=14 | |
| *A.prostrata* | 2x=14 | $A_PA_P$ |
| *A.wiestii* | 2x=14 | AsAs |
| Section Ethiopica | | |
| *A.abyssinica* | 4x=28 | AABB |
| *A.vaviloviana* | 4x=28 | AABB |
| Section Pachycarpa | | |
| *A.moroccana* | 4x=28 | AACC |
| *A.murphyi* | 4x=28 | AACC |
| Section Avena | | |
| *A. atherantha* | 6x=42 | AACCDD |
| *A. fatua* | 6x=42 | AACCDD |
| *A. hybrid* | 6x=42 | AACCDD |
| *A. occidentalis* | 6x=42 | AACCDD |
| *A. sativa* | 6x=42 | AACCDD |
| *A. sterilis* | 6x=42 | AACCDD |
| *A. trichophylla* | 6x=42 | AACCDD |

**Table.2** Extraction of beta glucan by different methods

| β-glucans (g/100g | Method | Reference |
|---|---|---|
| 10.9–1.0[b] | Enzymic | Lambo*et al.*, |
| 4.0 ± 0.1[a] | enzymic + HPAEC- | (2005) Johansson |
| 4.1 ± 0.19[a] | PAD Enzymic | *et al.*, (2004) |
| 10.37[b] | Enzymic | Genc*et al.*, (2001) |
| | alkaline extraction | Dongowski*et al.*, |
| 2.47–3.45[a] | Enzymic | Weightman*et al.*, |
| 1.73–5.7[a] | Enzymic | Havrlentova and Kraic |
| 13.79–33.73[b] | enzymatic-gravimetric | Gajdošova (2007) |
| Beta-glucan % | | |
| 3.77-8.56(Parents) | Enzymic | Ahmad and Zaffar |
| | Enzymic | Ahmad *et al*., (2015c) |
| 3.98-10.23 (F1s) | | |

[a]soluble β-glucan, [b]total β-glucan; HPAEC-PAD – high performance anion exchange chromatography with pulsed amperometric detection

**CROSSING PROGRAMME**

**Table.3** Fibre content in different oat-based food products

| | Food | Solubleβ-glucanss | Reference |
|---|---|---|---|
| Oats | whole meal | 2.66 | Gajdošova (2007) |
| | | 4.51 | Grausgruber *et al.*, (2004) |
| | Groat | 3.16 | Gajdošova (2007) |
| | | 3.5-5.0 | Malkki and Virtanen (2001) |
| | bran concentrate | 7.48 | Gajdošova (2007) |
| | | 11.5-17.0 | Malkki and Virtanen (2001) |
| | Flakes | 2.64-4.6 | Havrlentova and Kraic (2006) |

**Table.3** Fibre content in different oat-based food products

| | Food products | Solubleβ-glucanss (g/100g dry | Reference |
|---|---|---|---|
| Oats | whole meal | 2.66 | Gajdošova (2007) |
| | | 4.51 | Grausgruber*et al.*, (2004) |
| | Groat | 3.16 | Gajdošova (2007) |
| | | 3.5-5.0 | Malkki and Virtanen (2001) |
| | bran concentrate | 7.48 | Gajdošova (2007) |
| | | 11.5-17.0 | Malkki and Virtanen (2001) |
| | Flakes | 2.64-4.6 | Havrlentova and Kraic (2006) |

**Table.4** Oats nutritional value per 100 grams

| | | | |
|---|---|---|---|
| Vitamin C | 0 mg | Tryptophan | 0.234 g |
| Thiamin | 0.763 | Threonine | 0.575 g |
| Riboflavin | 0.139 | Isoleucine | 0.694 g |
| Niacin | 0.961 | Leucine | 1.284 g |
| Pantothenic | 1.349 | Lysine | 0.701 g |
| Vitamin B-6 | 0.119 | Methionine | 0.312 g |
| Total folate | 56 mcg | Cystine | 0.408 g |
| Vitamin B- | 0 mcg | Phenylalani | 0.985 g |
| Vitamin A | 0 IU | Tyrosine | 0.573 g |
| Retinol | 0 mcg | Valine | 0.937 g |
| | | Arginine | 1.192 g |
| | | Histidine | 0.405 g |
| | | Alanine | 0.881 g |
| | | Aspartic | 1.448 g |
| | | Glutamic | 3.712 g |
| | | Glycine | 0.841 g |
| | | Proline | 0.934 g |
| | | Serine | 0.750 g |

**Data source:** USDA National Nutrient Database

Previous and recent research is focused to explore the ways to incorporate *β*-glucans into various food systems (Hallfrisch and Behall, 1997; Ahmad *et al.,* 2008). In this context, *β* glucan is extracted from different sources and marketed in various forms such as *β*-glucan concentrate extracted from oats ("Oattrime"), *β*-glucan from barley ("Nutrim Xe") and *β* glucan extracted from rice ("Ricetrim") (Inglett *et al.,* 2004).

Arabinoxyan and *β* glucan when incorporated into flour for preparation of bread (Trogh *et al.,* 2004; Ahmad *et al.,* 2008), this addition not only markedly improved the loaf volume of bread (Ahmad and Zaffar, 2014a), but also increased the soluble fiber (Trogh *et al.,* 2004) and firmness of the bread crumb (Lazaridou *et al.,* 2007). Addition of *β*-glucan from barley and oat sources was recently reported by Kalinga and Mishra (2010) with promising rheological and physical properties of cake batter. In another attempt, enrichment of bread (at 2.5 and 5%) using purified barley *β*-glucan fractions was evaluated for in vitro digestion process. This resulted in significant reduction in starch breakdown and this degradation is proportional to the amount of *β*-glucan incorporated into the breads (Symons and Brennan, 2004). High-fiber diets and foods with low glycemic index may act a sprophylactic against prevention and treatment of coronary heart diseases and diabetes (Jinshui *et al.,* 2002; Granfeldt *et al.,* 2008). Incorporation of *β*-glucan into pasta products revealed a lower glycemic response (Yokoyama *et al.,* 1997). Similarly, a reduced glycemic index was reported in *β*-glucanen riched breakfast bar (Jenkins *et al.,* 2002) and *β*-glucan containing bread (Cavallero *et al.,* 2002). *β*-glucan has various applications in the food process industry including the bread and baking industry as thicken- ing agents for increasing viscosity, fat substitutes, as sources of dietary fiber, and for improvement of rheological properties (Ahmad *et al.,* 2008; 2010; Andersson *et al.,* 2009). Wheat flour, which is a poor source of dietary fiber (Dziezak, 1987) can be fortified by incorporating *β*-glucan for preparation of bread and other products (Ahmad *et al.,* 2015b; Trogh *et al.,* 2004). This incorporation of *β*- glucan in breads have a capacity to slow down the release of reducing sugars (in vitro) and consequently, increase the starch availability for digestion ultimately reduce the hyperglycemic and hyper insulinemic conditions (Brennan and Cleary, 2007; Thondre and Henry, 2009). This inclusion of *β*-glucan also improves the bread physiochemical characteristics (Cavallero *et al.,* 2002), viscoelastic (Skendi *et al.,* 2010), rheological and sensory properties (Flander *et al.,* 2007; Skendi *et al.,* 2010). There are controversial results for loaf volume; incorporation of *β*-glucan reduce the loaf volume (Rudel, 1990) by binding of large amounts of water so that limited amounts of water was available for the development of the gluten network and hence reduced loaf volume and tough textures was reported (Pomeranz *et al.,* 1977). On the contrary, Yun-Hyoung *et al.,* (2006) showed an improvement in loaf volume, and the textu-ral and sensory properties of milky bread by incorporation of *β*-glucan. Enzymatic degradation of *β*-glucan during process- ing is a common problem during bread preparation (Cavallero *et al.,* 2002; Moriartey *et al.,* 2010) but it can be avoided by the use of coarse flour thereby providing protection to *β*-glucan from enzymatic degradation (Flander *et al.,* 2007). The use of *β*-glucan is not only confined to cereal based products but its incorporation was also evaluated in beverages (Lyly *et al.,* 2003; Temelli *et al.,* 2004) and dairy based products (Konuklar *et al.,* 2004), it can also find some applications in the manufacture of low-fat ice creams and yogurts (Brennan *et al.,* 2002) and it can also be incorporated in combination with other soluble dietary fiber into low fat dairy products and low fat cheese curds to improve gelation and rheological characteristics (Tudorica *et al.*, 2004). The incorporation of barley *β*-glucan in combination with whey protein into food products may help in the enrichment of the diet and assist in the prevention of certain diseases (Temelli *et al.*, 2004). More- over, better soups can be prepared with a reasonable amount of *β*-glucan (Lyly *et al.*, 2004; 2007). Ricetrim is another type of soluble *β*-glucan fiber extracted from rice and is used as fat replacer with a smooth mouth feel and texture. It is successfully used in cookies, pumpkin pudding, layer cake, dipforpot crust, taro custard, and sauté chicken curry (Inglett *et al.*, 2004).

In conclusion *β*-glucan is a valuable functional ingredient that can provide a better physiological response and have several health promoting applications. Its promising physiochemical characteristics favor its use in various food systems. Extraction conditions of- ten affect the quality, quantity, molecular weight, viscosities, and other physiochemical properties of *β*-glucan. Therefore, future are search should focus on developing and characterization of new extraction technologies. To achieve complete benefits of this important functional ingredient, it is imperative that future research should be aimed at utilization of *β*-glucan for the development of new products. Unexplored areas about health application need special attention. Similarly, more research is required to understand the mechanism by which *β*-glucan enhances the immune system.

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