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β–glucan: Health Benefits and Role in Food Industry - A Review

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Abstract

β-glucan is typically found in starchy endosperm and aleurone cell walls of commercially important cereals, such as oat, barley, rye, wheat and some microorganisms. Natural products containing fungal β-glucans have been consumed for probably thousands of years, especially in China and Japan for their role in improving general health. In recent years, β-glucans have been noted as potent stimulators of mammalian immune system, and now are used clinically in China and Japan. Among the products with β-glucans, Zymosan is a very potent immune stimulator that has been widely used in research. The water-soluble fiber (β-glucan) seems to improve blood glucose regulation and reduce serum cholesterol levels in diabetic and hypercholesterolemic patients. Such beneficial health effects have been attributed to the solubility of b-glucans in water and their capacity to form highly viscous solutions. In 1997, the US Food and Drug Administration (FDA) approved a health claim for the use of oat-based foods for lowering the risk of heart disease and passed a unique ruling that allowed oat bran to be registered as the first cholesterol-reducing food at a dosage of 3 g β-glucan per day, with a recommendation of 0.75 g of β-glucan per serving. In addition to the physiological benefits of the soluble dietary fiber, their action also includes the physiological effects associated with the consumption of insoluble fiber, such as an increase of faecal bulk and a ability to relieve constipation. The appearance of such ingredients in the market has recently stimulated the research and development of many novel food products rich in cereal β-glucans.

Keywords: Barley, β–glucan, Oats, Solubility, Viscosity.

Introduction

The acceptance of β-glucan as functional, bioactive ingredients has increased the popularity and consumption of cereal-based foods as well as of many other foods fortified with cell wall-enriched grain fractions, β-glucan concentrates and isolates. β-glucan is a polymer of D-glucose linked with glycosidic bonds at β (1 -3), (1-4), β (1-6) and is typically found in starchy endosperm and aleurone cell walls of commercially important cereals, such as oat, barley, rye and wheat. β-glucan is commercially derived from oats, barley, mushrooms and some microorganisms. In microorganisms and mushrooms, these compounds are found to have a linear chain of D-glucose linked in the β (1-3) position with various sized D-glucose branches linked to the main chain by β (1-6) linkages (Figure 1). β-glucan derived from cereals are polymers of D-glucose with β (1-3) and β (1-4) linkages (Figure 2). β-glucan constitutes 1 % of wheat grains, 3- 7% of oats and 5-11% of barley (Skendi et *aI*., 2003).

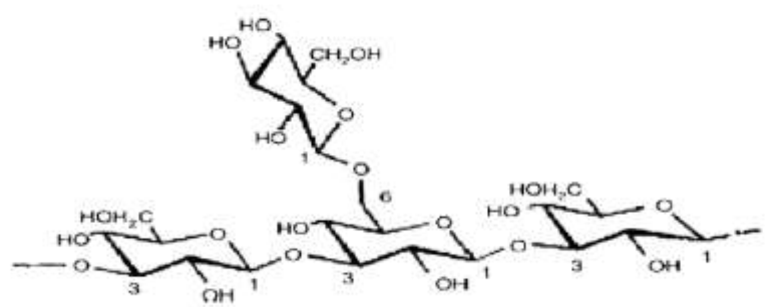

Figure-1.Structure of β (1 -3) β-glucan with branched β (1-6) present in oats and barley.

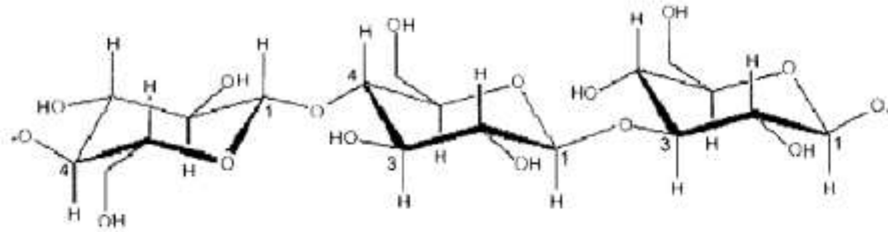

Figure-2. Structure of (1-3) β-glucan with branched with branched β (1-4) present in oats and barley.

β-glucan is generally obtained from cereal grains by dry milling (pin or roller), sieving, and air classification processes (Izydorczyk *et al*., 2003; Knuckles and Chiu, 1995; Vasanthan and Bhatty, 1995) or wet milling, sieving, and solvent-extraction protocols using different solvent systems (Beer *et al*., 1996; Bhatty, 1995; Cavallero *et al*., 2002; Jaskari *et al*., 1995; Oste Triantafyllou, 2000; Wood *et al*., 1989). These approaches result in concentrates or isolates containing approximately 8–30% β-glucan for the former and up to 95% for the latter. These approaches result in concentrates or isolates containing approximately 8–30% β-glucan for the former and up to 95% for the latter. The appearance of such ingredients in the market has recently stimulated the research and development of many novel food products rich in cereal β-glucan. From a nutritional and a functional viewpoint, such foods fit into the description of 'functional foods' as they provide some of the normal quality attributes of a food, such as mouthfeel and texture, as well as conferring specific health benefits. The water-soluble fibre seems to improve blood glucose regulation and reduce serum cholesterol levels in diabetic and hypercholesterolemic subjects, respectively. Such beneficial health effects have been attributed to the solubility of β-glucan in water and their capacity to form highly viscous solutions (Kahlon *et al*., 1993; Wood *et al*., 1994). In 1997, the US Food and Drug Administration (FDA) approved a health claim for the use of oat-based foods for lowering the risk of heart disease and passed a unique ruling that allowed oat bran to be registered as the first cholesterol-reducing food at a dosage of 3 g β-glucan per day, with a recommendation of 0.75 g of b-glucan per serving (Anonymous, 1997). Recently, a similar health claim for the barley β-glucan has also been approved (Anonymous, 2005). However, cereal β-glucan exhibit only partial solubility in water. Therefore, in addition to the physiological benefits of the soluble dietary fibre, their action also includes the physiological effects associated with the consumption of insoluble fibre, such as an increase of faecal bulk and on ability to relieve constipation.

Major Sources of β-glucan

Barley *(Hordeum vulgare)*

Barley, one of the ancient crops in the world, belongs to the genus *Hordeum* (Bothmer & Jacobson, 1985). It is used as animal feed, and for malting as brewing substrates for whiskey and beer fermentation and adjuvants for bread flour. Barley seed produces fiber in the hull, pericarp, and the cell walls of the aleurone and starchy endosperm. Cellulose is the major component of the hull, while arabinoxylan and β-glucan are the major components of the aleurone and starchy endosperm cell walls respectively. Scanning microspectrofluorometry of barley seed cross section confirms high concentration of β-glucan in the central endosperm (Xue *et al*., 1997; Fincher *et al*., 1992; Miller *et al*., 1994) Hull and starchy endosperm represent 85% of the seed, thus the composition of whole grain dietary fiber is strongly influenced by these two sources. β-glucan and arabinoxylan are the primary components of soluble fiber in barley. High levels of β-glucan have been associated with poor malt quality, thus the emphasis in cultivator development has been for low β-glucan or high β-glucanase enzyme. But β-glucan is also associated with many of the beneficial health effects of barley (Kahlon *et al*., 1996; Mcintosh *et al*., 1995) and this has promoted interest in high β-glucan cultivators.

Oat *(Avena sativa)*

Oats belong to the genus *Avena* and are considered a minor cereal crop based on annual production. It is primarily used as an animal feed, but it is gaining popularity as a breakfast cereal in forms like oat meal, ready-to-eat cereal and cereal bars. Oats are a good source of β-glucan and as such a good source of dietary fiber (Weightman *et aI*, 2002, 2004). β-glucan is a principal of oat soluble fiber which is a linear polysaccharide (1-3), (1-4)- β-D-glucan. It is located in endosperm cell walls, which are thickest adjacent to thr aleurone layer, in the subaleurone layer. The size of the endosperm cells, the thickness of the cell walls throughout the groat and the distribution of β-glucan vary among the different cultivar varieties (Bjorck *et al*., 1990). The total β-glucan content of oat groats is influenced by both genetic and environmental factors, the genetic influence being the greatest (Bjorck *et al*., 1990; Boros *et al*., 1996; Fastnaught *et al*., 1996) . Reported that β-glucan contents of oats vary from 1.8 to 8.5%, but the varieties having the highest beta glucan content are not commonly cultivated, and the in the oat trade the content of β-glucan varies from 3.5 to 5.5%.

Presence of β-glucan in other cereals.

A lot of sources for β-glucan are documented by the researchers and some of them are presented in Table 1 along with average β-glucan content in these sources. The major sources for this valuable functional ingredient include cereals and among the cereals oat and barley have higher β-glucan content. In cereal grains, the highest content of β-glucan is found in barley (2 - 11 %) and oats (2 - 7.5 %), while for wheat and rye it is a less abundant constituent and may range from 0.5-1 % and 1.4-2.6 %, respectively (Henery *et al*., 1987; Ahmad *et al*., 2010; Nilsson *et al*., 1997). Among these sources β-glucan content may differ from cultivar to cultivar (Ahmad *et al*., 2010) but environmental factor sometime have little effect and some time significant effect on β-glucan content from these sources (Stuart *et al*., 1998). The waxy genotypes of barley are characterized for higher levels of amylose with low starch and high β-glucans content (Anker *et al*., 2006). The highly significant interaction between cultivars and environment suggests that it is important to plant the appropriate cultivar in a particular area in order to obtain barley seeds with reasonable β-glucan content. Most important factors that can affect the recovery of β-glucan is the selection of source from which β-glucan can be extracted, other factors are extraction methods, extraction conditions, cultivar, location of origin and method of purification. Some relationships exist between grain β-glucan content and some agronomic traits; generally, high nitrogen levels increased barley grain β-glucan content (Brunner *et al*., 1993).

Table1: β-glucan content from different sources.

Sources	β -glucan content (%)	References
Flax	0.3-0.7	(Demirbas, 2005; Carter, 2005)
Lentils	0.4-1.1	Demirbas (2005)
Millets	0.5-1.0	Demirbas (2005)
Peas	0.3-0.7	Demirbas (2005)
Rice	0.4-0.9	Demirbas (2005)
Rye	0.7-2.4	(Demirbas, 2005; Gene, 2001)
Spring Wheat	0.6-1.1	(Demirbas, 2005; Cui *et al*., 2009)
Winter Wheat	0.4-1.4	(Hozova *et al*., 2007)
Hulless barley	3.7-9	Bhatty (1992)
Barley	5-10	(Mclntosh ,2001; Skendi *et al*., 2003)
Oats	3-7	(Bhatty, 1992; Demirbas, 2005; Braaten, *et al*., 1994; Skendi *et al*., 2003)
Beans	2.4-3.5	Demirbas (2005)
Corn/Maize	0.1-2.3	(Demirbas, 2005; Blakeney, 2005)

β-glucans extraction

Basics steps of β-glucans extraction (R.S Bhatty, 1995)

Barley / Oat Bran + solvent (As per methods and extraction conditions)

↓

Centrifuge at 6,000 X g for 15 min

↓

Combine supernatants, where necessary,
adjust to pH 4.5 with 2M HC1

↓

Centrifuge at 6,000 X g for 15 min, discard pellet

↓
Add Termamyl (1 ml/ 100 ml of supernatant), incubate
at 960 C for 1 hr with shaking
↓
Centrifuge at 6,000 X g for 15 min, discard pellet
↓
Add ethanol to 50% concentration, let sit overnight at 4°C
↓
Centrifuge at 6,000 X g for 15 min
↓
Resuspend pellet in H20, wash 2X with *50%* ethanol,
centrifuge, homogenize pellet in water, freeze-dry

Extraction of β-glucans form cereals has to deal with several difficulties. A typical extraction process involves, at least, three stages : inactivation of endogenous enzymes, extraction of β-glucans with a suitable solvent, and finally a purification-isolation stage, because other chemicals present in cereals (proteins, saccharides, or starch) can be coextracted (Bhatty R.S, 1995: Laroche *et al*., 1997). All these stages increase the complexity of the overall process, increasing the economical costs, therefore. This is the most limiting factor for the extraction process. When a solid-liquid extraction process is carried out, temperature, pH, extraction time and polarity of the solvent are some of the operating parameters that are to be taken into account. It is important to characterize the behaviour of the target compound when changing the operating variables, in order to improve the extraction process

Physical properties of β-glucan

Viscosity

Allmost all water-soluble polysaccharides produce viscous solutions. Viscosity is caused by physical interactions between polysaccharides molecules in solution- in general term molecules becomes entangales (Glicksman, 1969; Grassley, 1974). Oat β-glucans is able to form high viscous solutions in low concentrations. The viscosity of β-glucan depends on the molecular weight, solubility and concentration (Autio, 1996; Wood and Beer, 1998; Wood *et al*., 2000). High molecular weight beta glucan forms viscous pseudoplasdtic solutions, whereas low molecular weight beta glucans foms soft gels in higher concentration (Doublier and woods, 1995). Increasing the concentration of a dissolved polymer generally give rise to increase viscosity, as dose increases the molecular weight of the solute. The mixed linkage (1→3)(1→4)-β-D-glucans (β-glucans) in barley and oat are water-soluble, high molecular-weight polysaccharides (Wood, 1986). β-glucans result in viscous and shear thinning solutions even at quite low concentrations (Wood and Beer, 1998). Therefore, they are suitable alternatives for thickening agents in foods, e.g. beverages (Temelli *et al*., 2004), sauces, salad dressings and ice creams (Wood, 1986). For example, at above a 0.5% concentration, barley β-glucan was found to produce a higher viscosity than pectin at the same concentration (Temelli *et al*., 2004). Oat β-glucans generally have a higher molecular weight than barley β-glucan (Wood *et al*., 1991; Autio, 1996; Beer *et al*., 1997). This difference between barley and oat β-glucan is relevant to consider in their behaviour in foods (Brennan and Cleary, 2005). However, as regards the physiological characteristics of oat and barley β-glucans, they have been reported to have a quite similar efficacy (Delaney *et al*., 2003; Hallfrisch *et al*., 2003). Processing may effect the physiochemical properties such as solubility and molecular weight, and contributes viscosity in foods with high β-glucan.

Solubility

Solubility is the major factor in the nutritional properties of β-glucan. Soluble fiber influences plasma lipids and protects against cardiovascular disease, insoluble fiber promotes laxation and appears to be protective against colorectal cancer. Soluble fiber is a complex mixture of different polysaccharide of different molecular weights. Soluble fiber is generally hydrated in water, and if the conditions are right, some or all the polysaccharides molecules may go into true solutions. Some polysaccharides are soluble in water and other are not in molecular structure. For example – cellulose, which is insoluble in water whereas β-glucan from oats and barley is soluble in water. Cellulose has exclusively β-(1-4) linkages, whereas β-glucan have mixed β-(-4) and β-(1-3) linkages. Cellulose's regularity enables it to adopt ordered crystalline structures of polysaccharides chains held together by hydrogen bonds (Rees *et al*., 1977)**.** The ordered structures are insoluble (Morris *et al*., 1989). The irregular structure of the β-glucan prevents the formation of ordered crystalline structures, so these polysaccharides tend to water soluble. Similarly, branched structures, as the arabinoxylans in wheat, are unable to adopt ordered crystalline structures, and these compounds are also water soluble.

Water-Holding Capacity

β-glucans have a high water holding capacity and have a great role in various food applications as a soluble fiber. A high water holding capacity also helps to retard staling, control moisture migration and ice crystal formation, increase freeze/ thaw stability, and reduce syneresis or weeping (Kulp and Joseph, 2014).

Polysaccharides are hydrophilic molecules, they have numerous hydroxyl groups, which can form hydrogen bonds with water. Consequently soluble and insoluble polysaccharides alike have the ability to hold water. The most obvious demonstration of the ability of soluble polysaccharide to hold water is the phenomenon of gelation. A relatively small amount of polysaccharides, such as 1% agarose, can be enough to entrap the water in which it is dissolved in a three-dimensional network of polysaccharide molecules. The water is held within the polysaccharide matrix, unable to flow away, and the system has the semisolid properties characteristic gel. Insoluble fibers can also absorb water, but more in manner of sponge. They also foem a hydrophilic matrix in which water is entrapped, but where the quasi-crystallinity of the polysaccharide remains and water fills the interstics, often causing considerable swelling (Kulp and Joseph, 2014).

Health effects of Beta glucan

A lot of health benefits of Beta glucan are documented in scientific literature. The health effects of oat and barley β-glucans have been studied since the 1970s.The major health benefits are associated to the dietary fiber nature of this functional ingredient (Ahmad *et al*., 2012). Dietary fiber is the part of the food that resist digestion in small intestine but micro flora in large intestine partially ferments it. On the basis of functionality, it can be classified as soluble dietary fiber (SDF) and insoluble dietary fiber (IDF). Extracted β-glucan from cereal and other sources have the characteristics of both SDF and IDF. Cereals containing a wide range of macro and micro nutrients are used as a vehicle for nutrient fortification. Enrichment of foods by addition of high-fiber cereal grain containing β-glucan components is one way to increase fiber intake that may be helpful in reduction of bowel transit time, prevention of constipation, reduction in risk of colorectal cancer and promotion of the growth of beneficial gut micro flora (Davidson *et al*., 1991). Based on these health implications, FDA in its judgment accepted the health claims for dietary fibers including β-glucan from barley and oat. Similar health claims are also associated with flax fiber and soybean (Kurtzweil *et al*., 1998). β-glucan from barley and oats has good cholesterol lowering characteristics. A lot of mechanisms for cholesterol lowering are explained, but consumption or removal of precursor for cholesterol is the most accepted fact that may elucidate the effectiveness of β-glucan as cholesterol lowering agent (Davidson *et al*., 1991). Cereal β-glucan is highly effective in lowering both LDL, total cholesterol and serum triglyceride (Pomeroy *et al*., 2001). An increased level of faecal bulk is associated with prevention of some major disorders. Consumption of dietary fiber including β-glucan may result in higher viscosity of intestinal contents and increase faecal bulk (Wang *et al*., 2002). Higher viscosity of β-glucan is also responsible for appetite suppression, this property is ideal for persons who want to reduce weight. Viscosity property is largely dependent upon molecular weight of extracted β-glucan. In general, higher the molecular weight the more will be the viscosity and gelling property and this happens beacause of the more linkages in the chain (Volikakia *et al*., 2004). The solubility and concentration are other factors that may affect the viscous nature of the β-glucan in solutions (Burkus *et al*., 2005).

β-Glucan showed prebiotic characteristics when incorporated in food products. There is growing market for food products having probiotics and prebiotics in their formulation. Such products are available in large food stores across the world in the form of fresh milk, yougurts, kefir products, fruit juices (Tomasik *et al*., 2003). The prebiotic action in synergism to probiotics has major implications in maintaining gut health (Warrand *et al*., 2006). In fact, some prebiotics undergo fermentation by beneficial microflora in the large intestine and produce beneficial substances that are important for better gut health (Tomasik *et al*., 2003). The major products of fermentation by gut microflora are the short chain fatty acids (SCFA) along with production of vitamins, butyrate and some other vital nutrients (Warrand *et al*., 2006).

β‑glucan role in food industry:

Polysaccharide nature of β‑(1,3) glucans have found a wide range of potential applications in food industry, like in edible films, feed for domestic animals and low calorie food. There is some scope in the area of research in glucan gelling properties. Curdlan, a neutral gel forming linear β‑(1,3) glucan produced in Agrobacterium species, has been used as a biothickening and gelling agent in foods. Apart from being tasteless, colorless and odorless, studies have shown that heating process can produce different forms of curdlan gel with different textural qualities, physical stabilities and water holding capacities. A prospective research area is to exploit these properties of Curdlan and other β‑glucans to synthesize gels of differing strength for incorporation into gums for value added food products. An area of research for glucans in food industry is its application as an adjuvant for delivery of active compounds. Glucans can act as capsules or "tablet like" ingredients which can deliver their content further, after ingestion. They are non protein, heat resistant capsule that could be filled with any product. A few experiments by Ono et al. (1996) and Shiomi *et al*., (2005) have already shown the promise offered by glucans in this regard. When it comes to non fat products, cereal β ‑ glucan can be of use as soluble dietary fibre and as such can open avenues of research in food industry as stabilizer in low fat products such as salad dressings, ice creams, yoghurts and cheese. This way, scientists could explore how β ‑ glucans could help decrease the calorie content of food, as well as have beneficial effects on their gelation and rheological characteristics.

Several researchers incorporated β-glucan in cereal based, meat based and dairy based products (Lazaridou *et al*., 2007; cavallero *et al*., 2002) but still more investigations are required to better understand the role of this ingredient in other products. For instance, molecular weight profile of β-glucan has multidimensional effect on product development. It may affect the viscous nature, gel formation, rheological properties and other industrial important properties (Izydorczyk *et al*., 2008). White bread when prepared with traditional recipe will be always lacking dietary fiber. But there always exist a demand for high fiber white bread. Such type of bread is possible with inclusion of 'Glucagel' that is the trade name for beta glucan preparation extracted from barley. *In vitro* analysis of these bread samples revealed a significant decrease in reducing sugar release over a 300 m digestion in breads supplemented with 5% Glucagel sample. However, incorporation of Glucagel increase starch availability for digestion. This has implications in the reduction of hyperglycemia and hyperinsulinemia, with reference to the control of diabetes (Brennan *et al*., 2007). Similar to 'Glucagel' another commercial soluble fiber brand 'Ricetrim' is available in Asian markets. This brand is made up of rice bran and barley flour and is a good source of β-glucan. It may also utilize as fat replacer for the manufacturing of coconut cream with good rheological properties. Other usage includes Cookies, pumpkin pudding, layer cake, dip for pot crust, taro custard and saute and chicken curry (Inglett *et al*., 2004). Another reason for incorporating β-glucan in cereal products is the better visocoelastic properties in the dough that facilitate during mixing and proofing operations, as a result of this processor can achieve optimum bread crumb softness (Dubois *et al*., 1978).This incorporation in cereal products also adds value to the organoleptic properties in the final product (Ahmad, 2010). In an attempt to produce acceptable pasta products by using β-glucan containing barley flour Knuckles *et al*., (1997) prepared a pasta product having a good source of dietary fiber containing 5.8 g dietary fiber compared to less than 2 g in the same product conventionally made by all wheat flour. This product still has good acceptability as determined by organoleptic tests (Knuckles *et al*., 1997). Molecular weight is much more important to understand industrial application of β-glucan. β-glucans preparartion with molecular weight up to 3 million Da Knuckles et al. (1991) is considered larger molecules and have tendency to introduce high viscosity in the products. This higher viscosity is attributed to very strong intramolecular associations within the same molecule or with intermolecular association with other constituents of the product. It is possible to make pseudoplastic solution by the use of β-glucan; these solutions have greater importance in food industry. The application of low molecular weight β-glucans (9000 Da) seems to be appropriate for manufacturing of soft gels as these type of β-glucan molecules easily rearrange themselves due to less linkages Knuckles *et al*., (1997). The viscosity in low molecular weight β-glucan systems is dependent on molecular weight, concentration and solubility (Wood *et al*., 2000). Depending on molecular weight it is possible to prepare thixotropic suspensions, viscoselastic food systems and pseudoplastic solutions (Inglett *et al*., 2004; Wang *et al*., 2002). This phenomenon is achieved due to exposure to physical forces and chemical or enzymatic hydrolysis that tends to alter the molecular size of β-glucan in range of 0.4–2 million Da that is suitable in most typical food preparations (Beer *et al*., 1997). Multi functional role of β-glucan in different food systems allow the processors to incorporate this valuable ingredient in range of products. That may include low fat ice-cream (Brennan *et al*., 2002), low fat cheese (Tudorica *et al*., 2002), soft brined cheeses (Volikakis *et al*., 2004) and low fat sausages (Morin *et el*., 2002). Other applications of β-glucan that are reported in past two decade are soups, sauces, beverages (Din *et al*., 2009; Lyly *et al*., 2007). When incorporated in such products that have the ability to replace conventional used thickeners (Giese, 1992). Processor may also consider the addition of β-glucan to achieve characteristics like improved viscosity, water-holding capacity, oil-binding capacity, emulsion stabilization and improvement in organoleptic characteristics of these products (Thammakiti *et al*., 2004; Ahmad *et al*., 2008; Ahmad *et al*., 2008; Ahmad *et al*., 2009).

β-glucan incorporation with different food products.

The potential use of β--glucans as a hydrocolloids in the food industry is based mainly on their rheological characteristics, i.e. their gelling capacity and ability to increase the viscosity of aqueous of solutions. Thus, β--glucans can be utilised as thickening agents to modify the texture and appearance of food formulations or may be used as fat mimetics in the development of calorie-reduced foods. b-Glucan-rich fractions from cereals or purified β-glucans have in fact been successfully incorporated into products such as breakfast cereals, pasta, noodles and baked goods (bread, muffins), as well as dairy and meat products (Cavallero *et al*., 2002; Dexter *et al*., 2004; Duss and Nyberg, 2004; Hatcher *et al*., 2005; Hudson *et al*., 1992; Inglett, 1990; Newman *et al*., 1990). The incorporation of fractions enriched with oats and barley β-glucans into cereal-based foods has been widely studied. The addition of β-glucans concentrates at high levels (10–30%) in yeast-leavened breads leads to high water retention, as well as to darker coloured end-products and undesirable effects on crumb texture and loaf volume (Bhatty, 1986; Cavallero *et al*., 2002; Dexter *et al.*, 2004; Izydorczyk and Dexter, 2004; Krishnan *et al*., 1987; Newman *et al*., 1998). However, b-glucan rich fractions from oats and barley may result in increased loaf volumes when used at certain concentrations in wheat flour, probably by increasing the viscosity of the dough (Delcour *et al*., 1991). It is considered that β-glucans may play a role in improvement of bread crumb structure by stabilising air cells in the dough and preventing their coalescence (Wang *et al*., 1998). Relationships have also been established between β-glucans concentration and the pasting characteristics of oat flours. The increase in the pasting peak viscosity which occurred with increasing β-glucan content of oat cultivars was explained by an increase in the water binding capacity of the flours (Sirghie *et al*., 2004; Zhou *et al*., 2000). In addition to the polysaccharide concentration, the molecular weight (Mw) also seems to affect the bread making performance of β-glucan, as shown in a recent investigation (Skendi *et al*., 2006) in which two isolates of barley β-glucan with different molecular weights were incorporated into breads made from two types of wheat flour differing in their bread making quality. The addition of β-glucan with high molecular weight resulted in higher loaf volumes than the incorporation of those with low molecular weight. The highest loaf volume was obtained for the poor bread making quality flour with 0.6% w/w β-glucan, with the incorporation of the high molecular weight preparation giving quality exceeding that of the good breadmaking quality wheat cultivar. Furthermore, incorporation of β-glucans up to 5% into baked goods, such as muffins, did not seem to affect the overall acceptability of the products (Hudson *et al*., 1992; Newman *et al*., 1990, 1998). The addition of barley fractions enriched in β-glucans in semolina or wheat flours at up to 20%, resulted in pasta or noodles with acceptable sensory properties and cooking quality despite their decreased brightness and yellowness and the increased redness and 'speckiness' of the product (Dexter *et al*., 2004; Hatcher *et al*., 2005; Izydorczyk *et al*., 2005; Marconi *et al*., 2000).

Food formulation also has an impact on the gelation ability and the rheological properties of cereal β-glucans gels (Irakli *et al*., 2004; Lazaridou and Biliaderis, 2007; Lazaridou *et al*., 2007; Vaikousi and Biliaderis, 2005). The incorporation of various sugars (glucose, fructose, sucrose, xylose, and ribose) at a concentration of 30% (w/v) to aqueous dispersions of barley b-glucan (6% w/v) led to an increase of the gelation time upon curing at room temperature (Irakli *et al*., 2004). Similarly, the addition of several sugars (sucrose, glucose, fructose, and xylose) at a concentration range of 5–30% (w/w) to aqueous dispersions of β-glucans (3% w/w) without or with skimmed milk (12% w/w), submitted to repeated cycles of freezing– thawing, induced a significant delay in the transition to a gel state. The resultant cryogels were weaker (Lazaridou and Biliaderis, 2007; Lazaridou *et al*., 2007; Vaikousi and Biliaderis, 2005) and the inhibitory effects of xylose and fructose were stronger than those of glucose and sucrose.

Cereal β-glucans exhibit the potential to be used as fat replacers due to their high viscosity and water binding and their foaming and emulsion stabilising capabilities (Burkus and Temelli, 2000; Kontogiorgos *et al*., 2004). Kontogiorgos *et al*. (2004) investigated the effects of pure barley and oat b-glucans on the rheological and creaming behaviour of concentrated egg-yolk-stabilised model emulsions (salad dressing model). They observed that the high molecular weight β--glucans (apparent Mw-110-103) stabilized the oil-in water (o/w) emulsions, mainly by increasing the viscosity of the continuous phase, while the low molecular weight β-glucans (apparent peak Mw-40-103) influenced emulsion stability through network formation in the continuous phase. They also found that incorporation of barley β-glucans gum (76.2% purity) into reduced fat breakfast sausages at a level that provides 0.3–0.7% β-glucans in the product gave improved water binding, without having any significant effects on product texture or flavor at a level of 0.3% (Morin *et al*., 2002). A commercial concentrate of oat β-glucans (22.2% β-glucans content) has been also incorporated into low-fat white-brined cheese from bovine milk (70% fat reduction) at two levels, 0.7% and 1.4% (w/w), resulting in a product with increased yield, greater proteolysis and higher levels of short chain fatty acids (lactic, acetic, and butyric) as well as with improved texture compared to its low-fat (b-glucan-free) counterpart. However, the colour, flavour and overall impression scores were significantly inferior to those of a typical whitebrined cheese product, particularly for the cheese product made with the high level of β-glucans (Volikakis *et al*., 2004). Recently, non-dairy ready-to-use, lactose-free, milk substitutes (oat milk beverage, yogurt, ice cream, oat-based cream, whipped cream, and buttermilk) have been introduced into the market. These products contain cereal β-glucans as bioactive ingredients as well as acting as stabilisers and texturisers (Anonymous, 2003; Oste Triantafyllou, 2002). The molecular weight of β-glucans does not only affect the viscosity of foods but also has a significant impact on the perceived (sensory) thickness of products as shown for beverage and soup food prototypes containing 0.25–2% (w/w) β-glucans (Lyly *et al*., 2003, 2004). These appear to be significant correlations between textural characteristics and measured viscosity as well as a moderately strong relationship between flavor attributes and the viscosity of soups. From a technological point of view, β-glucans may be useful as alternative thickening agents in soups. It may also be possible to prepare beverages and soups containing a physiologically effective amount of β-glucans from low molecular weight b-glucan preparations, as they are easier to process than their high molecular weight counterparts.Similar to other cereals grains, barley can be minimally processed into flakes and grits to be utilized as a hot breakfast cereals or a baking ingredient (Alexander *et al*.,1994; Sundberg *et al*., 1994; Lewis *et al*., 1995). In fact a commercial barley meal similar to oatmeal has the heighest β-glucans content, 5.08 %,of all the commercial cereals sold in finland (Plammi *et al*., 1993). Flaked barley cereals made from waxy hulless barley sold in united state contain 7% β-glucans providing 2 gram per 1 oz. serving. Minimal processing also produce pearled barley most often found in soups and can provide 1-2 gram of β-glucans per 1 oz. serving depending on type of barley pearled .Extrution processing of barley for foods has significance benefits over other processing. High temperature and high pressure increase the solubility of β-glucans and can increase resistant starch producing an increase in both soluble and insoluble fibre of the products (Bergund *et al.*, 1992).

Noodles contain small amount of barley are reported to have acceptable cooking and sensory qualities and increased β-glucans contents. Baik and Czuchajowska, (1997) found that the texture profile analysis of udon noodles containing 15% ground pearled nonwaxy barley was similar to 100% wheat flour noodles but required a shorter cooking time . Barley β-glucans incorporated at a low levels in yeast bread is similar to other gums used as a gluten substitutes. Lee et al. (1995) reported that 1 % of an extracted 85% pure barley β-glucans increased water absorption and dough development time but improved bread grain and texture while maintaining loaf volume. Higher levels of β-glucans isolates (Knuckles *et al*., (1997; Bergund *et al.*, 1992; Mcintosh *et al.*, 1991) flours and bran (Rasco *et al.*, 1990) have been incorporated intobread to provide consumer with adequate levels of of fibre and β-glucans in their diet .All of these study have reported a decrease in loaf volume as barley β-glucans or fibre is increased in bread. Sensory test showed that bread with significance levels of β-glucans or fibre rated similar in overall acceptability to the control breads. Cookies, muffins ,quick breads and tortillas have been made using various levels of flours ,bran and concentrates. Berglund et al. (1992) incorporated 50-100% waxy hulless barley flour ,into cookies ,a no fat muffins and quick bread which were rated by consumer panels having overall acceptabilitiy similar to the control products. Muffins made with 100% barley flour (Newman *et al*., 1990) having β-glucans content ranging from 3.8 to 4.9% have been described as moister and gummier but were preffered over the wheat control.

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