Journal of Nutrition & Food Sciences
ISSN: 2155-9600

Ahmad et al., J Nutr Food Sci 2012, 2:2
DOI: 10.4172/2155-9600.1000133

Research Article

Open Access

Perspective of β-Glucan as Functional Ingredient for Food Industry

Asif Ahmad[1]*, Bushra Munir[2], Muhammad Abrar[4], Shaukat Bashir[1], Muhammad Adnan[3] and Tahira Tabassum[1]

[1]*Department of Food Technology, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, 46300, Pakistan*
[2]*Department of Chemistry & Biochemistry, University of Agriculture, Faisalabad, 38040, Paksitan*
[3]*Wheat Research Institute, Ayub Agriculture Research Institute, Faisalabad, 38040, Paksitan*
[4]*Food and Agriculture Section, Planning and Development Division, Pak Secretariat, Islamabad, 47000, Pakistan*

Abstract

β-Glucan is an important functional ingredient having many health benefits. A lot of sources for this valuable ingredient have been identified. β-Glucan from these sources may be extracted to fulfill the ever growing demand for nutraceutical product. The industrialists may also exploit this situation by using this functional ingredient for developing new nutraceutical products. Such products may provide health benefits beyond basic nutrition. Numerous health benefits of β-Glucan are documented in scientific literature that may range from simple stomach problem to complex defense shield against cancer. This review focuses on potential sources of β-glucan, health implications, industrial applications and immunomodulatory effect of β-glucan.

Keywords: β-glucan; Functional foods; Nutraceutical; Immunomodulation; Health benefits; Cholesterol; Food industry

Introduction

Growing interest in functional and nutraceutical product is seen in the last decade. This happened due to fast life style and concept of curing ailment through food. People all over the world have a quest for new options and concept of functional ingredient satisfy their dietary needs as these functional ingredients have a positive impact on metabolic parameters and ultimately helpful in curing chronic diseases such as diabetes, cardiovascular disease and cancer. Higher institutions all over the world are well aware of this fact and people needs. Therefore, they are developing policies to use these functional ingredients for the development of novel industrial products. For instance FDA authorized the use of health claims on the association of oat bran fiber, psyllium fiber and soy protein with coronary heart disease [1,2]. Food Industry is also in search of new nutraceutical ingredients that have documented health benefits along with better industrial application to the food product. The number of food products that can have health claims are limited at present and have a great potential for processor to occupy the market of such product that is at present in infancy.

Major food industry making use of functional ingredients is baking, beverage, meat, dairy and confectionary [3]. An annual growth rate for this industry is hitting at a figure of 7.4% that correspond to worth of more than 176 billion USD in the year 2013. Among all of this the major share is for beverage sector that is the fastest growing sector with an annual growth rate of 10.8%. This can experience more rise with more industrial innovation for the development of new functional foods that have a capacity to meet the consumer demand [4]. In Europe, functional dairy product occupied a market value of about 1345 million USD during the 2002-3 [5]. For this ever growing industry a lot of functional ingredients are available, some of these may include β-glucan, omega 3 fatty acids, theophyllin, antioxidants, DHA, EPA and β-glucan.

Chemically Beta glucan is a non starch polysaccharide with repeating units of glucose, these glucose units may branched in several ways depending upon the source from which it is extracted. The chemical structure revealed long chains of β-D-glucopyranose that are linked together through β-(1→3) linkage to form a long backbone whereas side chains arise through β-(1→4) linkage (Figure 1). The later may appear after 3-5 glucose units in the main backbone of β-(1→3) linkages. The structure of β-glucan molecule consists of predominantly β-(1→3)-linked cellotriosyl and cellotetraosyl units [6,7] with overall glucose residues may extend more than 250,000 [8].

A lot of sources for this functional ingredient have been documented including cereals, mushrooms, yeast, algae and beans. β-Glucan extracted from either of the sources provide most of the cholesterol-lowering properties. However, β-glucan extracted from mushrooms and from baker's yeast also serves as immune system booster in dietary supplements. Chemically cereal β-glucan differs from yeast β-glucan in having β-(1→3) and (1→4) linkages [7]. Whereas yeast β-glucan having β-(1→3) and (1→6) linkage that may provide it better immune boosting properties [8]. Moulds β-glucans have similar chemical structure as the baker`s yeast having long chains of about 1500 units of glucose arranged with β - (1→3) linkage and this represent about 85% of total cell wall β-glucans, and short chain of about 150 glucose units which is arranged in β–(1→6) fashion and this accounts for about 15% of the β -D-glucans [9].

A lot of health benefits of β-glucan reported in literature that showed its suitability for incorporating in various food products. Some of the health implications involve activity against colon cancer [10], depress hunger, better gut health [11], increased stool bulk and removal of toxic substances, anti-constipation agent [12], reduction

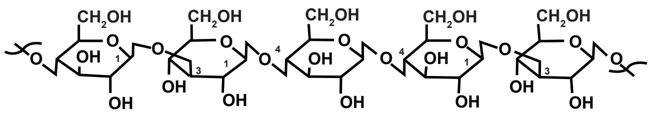

Figure 1: Structure of cereal β-.glucan.

***Corresponding author:** Asif Ahmad, Department of Food Technology, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, 46300, Pakistan, Tel: 92-334-5628182; E-mail: asifahmad_1@yahoo.com

Received January 06, 2012; **Accepted** March 07, 2012; **Published** March 12, 2012

Citation: Ahmad A, Munir B, Abrar M, Bashir S, Adnan M, et al. (2012) Perspective of β-Glucan as Functional Ingredient for Food Industry. J Nutr Food Sci 2:133. doi:10.4172/2155-9600.1000133

in glycemic index [13], reduction in serum cholesterol [14], leveling of postprandial glucose level [15] and prevention in coronary heart disease [16].

Health implication alone is probably not sufficient to use the β-glucan in large food industry. It should also possess some important characteristics that can attract processors and consumers. A lot of industrial applications explored for β-glucan addition in the food products. Of course that is due to its promising characteristics to be used as stabilizing agent, thickening agent, gelating agent and emulsification agent. These are some important industrial applied characteristics that can turn the raw material into novel food product such as functional beverage, functional bread, ready to serve soups, functional snack foods and variety of sauces and into a big list of other food products [17,18]. β-glucan is a major factor for controlling the quality of the product [19]. These are the some episodes from industrial applications. The industrial demand for this natural substance is fast growing. A lot of functional food products containing β-glucan are now being commercially introduced to the market [18,20] and their number will steadily increase in the future world market. The purpose of this article is to have an overview of β-glucan sources, health benefits associated with β-glucan, industrial applications and to understand the immunomodulating effect of β-glucan.

β-Glucan sources

A lot of sources for β-glucan are documented by the researchers; some 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 [21-24]. Among these sources β-glucan content may differ from cultivar to cultivar [25] but environmental factor sometime have little effect [26] and some time significant effect on β-glucan content from these sources [27]. The waxy genotypes of barley are characterized for higher levels of amylose with low starch and high β-glucans content [28]. 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 beta 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 [29]. Similarly, a negative correlation between irrigation and barley grain β-glucan exist [30]. For 164 cultivars, originating from China, β-glucan content ranged from 2.98% for Sumei 21 to 8.62% for QB25, with a mean of 4.58%. Tibet barleys, all of the hull-less type, had the highest β-glucan content. The seeds produced in Hangzhou had lower β-glucan contents than those produced locally [26]. Among other cereals, wheat also contain β-glucan but in very small amount that might be not feasible for commercial extraction [31]. Several researchers extracted β-glucan from rye [32] and rice, the later being marketed with the name of 'NutrimXe' [33]. During extraction of β-glucan from their respective sources, the extraction rate varies and depends upon on sources, temperature, pH [25,34]. From oat the extraction rate can be achieved from 50 to 80%, barley is another good source from which 70-80% β-glucan is extractable. Slightly higher recoveries experienced by using yeast source, it is observed that by using *Sacchromyces cerevisiae* up to 87% β-glucan is extractable [35].

Source	β-glucan content(%)	Reference
Beans	2.4-3.5	[44]
Canary seed	1.1-2.3	[44]
Corn/maize	0.1-1.3	[44, 45]
Flax	0.3-0.7	[44,46]
Lentils	0.4-1.1	[44]
Millet	0.5-1.0	[44]
Peas	0.3-0.7	[44]
Rice	0.4-0.9	[44]
Rye	0.7-2.4	[44, 47]
Spelt	0.6-1.2	[44,48]
Spring wheat	0.6-1.1	[44, 49]
Winter wheat	0.4-1.4	[48]
Hulless barley	3.7-9	[22]
Barley	5-10 %	[50]
Oat	3-7%	[22, 44, 51]
Barley mutant "(HiAmi x Cheri) x Cheri	7-12	[10]

Table 1: β-glucan content in different sources.

Among yeast *Sacchromyces cerevisiae* is the major source of β-glucan, other sources include *Zygosaccharomyces bailii*, *Kloeckera apiculata, Kluyveromyces marxianus, Debaryomyces hansenii, Kluyveromyces marxianus* and *Schizosaccharomyces pombe* [36]. The members of fungi group are also a good source of β-glucan. Among them researchers are focusing on edible fungi that are grown in the form of edible mushrooms. The most renowned mushroom sources include *Agaricus brasiliensis* [37], *Pleurotus tuberregium* [38], *Grifola frondosa* [39], *Lentinus edodes* [40], *Pleurotus eryngii and Pleurotus ostreatoroseus* [41]. A detail review of these mushrooms having β-glucan content is published by Lindequist [42] with reference to pharmacological importance. Other fungi sources that are not used as edible purpose can also be used for extraction of β-glucan that may include sources like *Termitomyces eurhizus* [43], *Penicillium chrysongenum* [16].

Health benefits

A lot of health benefits of β-glucan are documented in scientific literature. The major health benefits are associated to the dietary fiber nature of this functional ingredient [52]. 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. The health benefits associated with β-glucan has been previously confirmed in animal models [53] as well as in clinical trials on human beings [54]. Therefore development of β-glucan rich products which could potentially reduce the incidence or slow progression of chronic diseases is of chief importance. The concept of functional foods with the emphasis on disease prevention has been predominantly implemented to develop grain based foods which are highly regarded by nutritionists. 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 [55]. 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 [2].

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 [55]. Cereal β-glucan is highly effective in lowering both LDL, total cholesterol and serum triglycerides [56,57]. The cholesterol lowering property is dependent on molecular weight of the β-glucan. In a 10-week blinded controlled study the differences in high molecular weight (HMW) or low molecular weight (LMW) barley β-glucan (5 g dose level) on cholesterol level was explained. After completion of study period, the mean LDL-C levels fell by 15 and 13 % in the 5 g HMW and LMW group, respectively. Similar results were observed for total cholesterol [58]. In another study by Amundsen et al. [59] a 6% decrease in serum total cholesterol was recorded by consumption of same level (5 g) of β-glucan but from the oat source. There are evidences that circulating lipoproteins in form of LDL (bad cholesterol) or elevated levels of total cholesterol increase the risk of coronary heart diseases and lot of death are reported due to this risk factor [60]. Lowering of cholesterol through β-glucan consumption may provide a solution to this problem that may also reduce the risk of heart related disease [61].

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 [62]. 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 [63]. The solubility and concentration are other factors that may affect the viscous nature of the β-glucan in solutions [64].

In last two decades the term glycemic index (GI) is much popularized. This concept allows the ranking of foods based on glycemic impact. This will permit an individual to self control their diets according to their needs [65] and give an idea about the food that how speedy it will be digested and absorbed as glucose [66]. At present, limited nutraceutical food products are available in the markets that can positively alter the glycemic index. β-glucan is a potential candidate that has the capacity to develop such nutraceutical products with low glycemic index. The development of functional foods with low glycemic index will occupy a large market for diabetic consumers [67]. Kabir et al. [68] demonstrated that consumption of low-GI breakfast containing 3 g of β-glucan for 4 weeks is very effective to have good glycemic control along with lowering of plasma cholesterol levels in type 2 diabetic patients [68]. However, a slightly higher amount (10 g) of β-glucan is required to achieve same beneficial physiological response on postprandial glucose level in obese subjects that are suffering from problem of insulin resistance [69]. Some other researchers such as Poppitt et al. [70] also demonstrated a significant reduction in glycemic index over control when β-glucan was incorporated in meals. This change over control was no significant when β-glucan was incorporated in beverage. Overall, β-glucan from barley and oat is responsible for reduction in postprandial glucose level through controlling endocrine response and might be used for development of new nutarceutical products [11,70].

Regular consumption of β-glucan from either source may result in better gut health. β-glucan containing foods cause delay in emptying the gastric content and may result in slow absorption of nutrients [71]. Such foods have the capacity to alter the mixing pattern of intestinal contents thus modify the metabolism mechanism [72]. Increase in gut transit rate is a short term response that can be experienced by ingestion of β-glucan. This physiological response provide relief to patient of chronic constipation [71] and slow down the glucose and sterol absorption by the intestine [73,74]. At the same time β-glucan helps in binding excess bile acids and salts and interacts with mutagens and carcinogens in the gut for their efficient removal [71]. Positive effect of this polysaccharide was observed in patients with colorectal cancer where its consumption significantly prolongs the disease-free period [75]. The detail for anticancer activity of β-glucan is reported by Cheung et al., who studied the effect of β-glucan using the immune deficient xenograft tumor models that synergizes with anti-tumor monoclonal antibodies (mAb). The researchers also showed a good correlation between antitumor activity and the molecular size of the β-D-glucan irrespective of the fact whether it has got (1→3) (1→4) or (1→3) (1→6) linkages [76].

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 [77]. The prebiotic action in synergism to probiotics has major implications in maintaining gut health [71]. In fact, some prebiotics undergo fermentation by beneficial microflora in the large intestine and produce beneficial substances that are important for better gut health [77]. 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 [71].

Industrial applications

Food industry may take the advantage of this functional ingredient having ever growing market. Consumer demand for healthy and nutraceutical food is the major motive for this growth. To use this nutraceutical ingredient in true sense the purity of this ingredient should be at high level. This will ensure specific composition to achieve specific health benefits and remove doubts about which components are responsible for such effects. For instance the work conducted on barley or oat flour, and/or β-glucan enriched cereal flours, may not be directly comparable to the use of purified β-glucan fractions. This also leads to potential problems when incorporating these agents into food systems, in terms of predicting exact processing parameters [16]. The challenge now exists to optimize extraction procedures so as to produce consistent raw material. A lot of extraction and purification techniques were investigated by several researchers that may include hot water

Product	β-glucan content (%)	References
Cerogen™	70-90	[72,80]
Glucagel	75-80	[77,81]
Ceapro	94	[82]
OatVantage™	54	[55]
Viscofiber	50	[50]
C-trim50	48	[43]
C-trim30	32	[28]
C-trim20	21	[83]
Natureal®	20	[84]
Nature®	15	15

Table 2: Commercial β-glucan products.

extraction [57], enzymatic extraction [78], acidic extraction [25], alkaline extraction [79] and solvent extraction [22]. Each technique has its own merits and limitations. The commercial products available in the market vary in the method of β-glucan isolation, concentration, molecular weight, water holding capacity and viscosity. Some of the important commercial products of β-glucan along with β-glucan content are presented in Table 2.

Several researchers incorporated β-glucan in cereal based, meat based and dairy based products [81,85,86] 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 [87]. On the other hand it may also alter specific health benefits that are intended to achieve for a specific purpose. Further study also needed on the potential effects of incorporating β-glucan into both dairy and cereal-based food systems in reference to rheological characteristics and molecular profiles of β-glucan [16]. Such research would broaden our understanding of how β-glucan can affect the nutritional characteristics of foods by altering their structure, texture and viscosity. Relevant literature on β-glucan incorporation into finished products indicate the influence of various factors (molecular weight, solubility, concentration) in such products during processing operations. To ensure a better product during processing, the processor must pay attention to processing methods, functional properties of β-glucan, enzymatic and mechanical cleavage of β-glucan molecule. A close focus on these factors will allow the processor to produce a product with desirable features that have the capacity to meet consumer demand for nutraceutical food [88].

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 [89]. 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 sauté and chicken curry [33]. 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 [90]. This incorporation in cereal products also adds value to the organoleptic properties in the final product [25]. In an attempt to produce acceptable pasta products by using β-glucan containing barley flour Knuckles et al. [91] was able to produce pasta product. This product was 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 [91].

Dairy based products have a great potential to utilize β-glucan to develop new nutraceutical products. Bekers et al. [92] developed a new functional bioactive dairy based food containing oat β-glucan. This product address the idea of symbiotic combination of probiotics and prebiotics and dietary fiber is released during fermentation process [92]. Possibility of incorporation of oat based β-glucan for the development of functional yogurt also showed promising result. In such product, β-glucan addition improved the body and texture of unsweetened yogurts. Apparent viscosity was also increased but in combination with sweeteners [93]. Addition of β-glucan also stimulates the fermentative bacteria in the dairy products and produce functional bioactive substance [94].

Molecular weight is much more important to understand industrial application of β-glucan. β-glucans preparartion with molecular weight up to 3 million Da [95] 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. Such type of solution follows the power law and conditional for higher concentrations of β-glucan the Herschel–Bulkley model. The flow behaviour index varied from 0.97 and 0.31, indicating mild to highly pseudoplastic solutions of β-glucan, respectively, where the pseudoplasticity increased with the concentration [80]. 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 [96]. The viscosity in low molecular weight β-glucan systems is dependent on molecular weight, concentration and solubility [73]. Depending on molecular weight it is possible to prepare thixotropic suspensions, viscoselastic food systems and pseudoplastic solutions [33,16]. 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 [97].

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 [83], low fat cheese [19], soft brined cheeses [63] and low fat sausages [98]. There are also some indications that these molecules might have useful functional properties in food structures, for example in promoting whipping and emulsification [99,18]. Other applications of β-glucan that are reported in past two decade are soups, sauces, beverages [100,101]. When incorporated in such products that have the ability to replace conventional used thickeners [102]. 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 [103-105].

Immunomodulation effect of β-glucan

Beta glucan extracted from yeast and fungi have 1→3 backbone with side branches linked through 1→6 linkages. This chemical nature is very effective for immunomodulating affect of β-glucan. The mechanisms involving immunomodulation effect of β-glucan are depicted in Figure 1. Immunomodulation along with response modification have application in cancer patients where these serve as immunity booster in such patients and also reduce the side effects of chemotherapy [106]. Beta glucan in such patients improve the capacity of specific immune cells through release of cytokines, these cytokines transmit specific signals to other immune cells. Thus a cascade of information transduction system initiate that stimulate the entire immune system against unwanted cell growth. This has application in treatment of malignant tumor and cancerous growth. Beta glucan can produce both innate and acquired immune response through binding with macrophage, neutrophils and natural killer cells. An interaction of β-glucan with natural killer cell in T- lympohocyte system results in cytokine production that may cause lysis of infected cells and also activate innate immune response through macrophage [107].

Molecular and cellular level work for yeast β-glucan having 1→3 and 1→6 linkages indicate the possibility of β-glucan to act as antitumor agent and also bear good immunostimulants agent against infectious disease. Some researchers claimed these affects can be achievable through granulocutes stimulation, macrophages, monocytes and NK-cells [108]. These processes are further triggered through T cell response; as a result of thismacrophage more actively secrete IFN-g, IL-6, IL-8 and IL-12. Such tumorocidal roles are already confirmed by Bohn and BeMiller [109] while working on mice models. To achieve this immunomodulatory effect, the mode of adminstartion of β-glucan is very important that may affect the solubility of β-glucan. intravenously or intraperitoneally is the most used routes of administration. Insoluble β-glucan will be problematic if admintered through parenteral routes and may cause microembolization, granuloma formation, pain and severe inflammation [110]. To overcome these problems, an oral administration of the water-soluble glucan preparations is suggested. To overcome the problem of weak solubility, use of modified β-glucan is practical. In this case several chemically modified derivatives such ascarboxy-methylated β-glucan, sulfated β-glucan and phosphate β-glucan is more appropriate [111-113]. Some protective effect of sulfoethyl glucan (sulphur containing modified derivative of β-glucan) against mutagenicity induced by potassium bichromate in mice was also reported [114]. This derivative is also exhibited anti-infective activity against *Klebsiella pneumoniae* after intravenous or subcutaneous prophylactic application to mice [115].

Ingested or administrated β-glucan stimulate human monocytes, as a result of this stimulation cascade of reactions start that ultimately give birth to tumor necrosis factor-α (TNF-α) and interleukin-1β by a mechanism dependent on trypsinsensitive β-glucan receptors [116]. This mechanism initially involves binding of β-glucan on specific protein. Two substances *in viz*. vitronectin and fibronectin are identifed as major glucan binding proteins. A strong complex of β-glucan with these proteins ensures the relase of macrophage cytokines [117,118]. β-Glucan is important in control of several fungus diseases. It is well known that particulate consumption of β-glucan have a priming effect for IL-12 production that may be exploited for the control of Paracoccidioidomycosis that is an important fungal disease large spread in parts of Latin America [119]. Along with this immune boosting mechanism, soluble β-1→3-glucan in combination with other lipopolysaccharides enhances the IL-8 and IL-10 and monocyte activity within the effected tissues. This glucan complexes also strongly primed for TNF-α and IL-6 induction by LPS [120]. In another instance, Větvička et al. [121] showed that soluble CR3- specific polysaccharides such as β-glucan induce a primed state of CR3 that can trigger the killing of iC3btarget cells that were otherwise resistant to cytotoxicity [121]. Overall, β -glucan itself is non toxic against tumors but acting as response modifier and have immunostimulative action against tumor cells [122].

Conclusions and Implications

β-Glucan is a valuable functional ingredient that possesses numerous health benefits. Its role in controlling hyperglycemia and hyperlipedemia is extraordinary. Detailed mechanisms on these effects are well enumerated in previous literature. Recent research focus on β-glucan immunomodulatory effects with anticarcinogenic activity makes this substance valuable for future food and pharmaceutical industry. Industry can also take the benefits of its use as stabilizer, viscosity enhancer, fat replacer, gelling agent and plasticizing agent. Despite the numerous applications, challenges still exists for its extraction and purification. New product development on the basis of molecular weight characterization of β-glucan is another avenue for future investigations. Overall β-glucan possesses multidimensional characteristics to be added as functional ingredient in foods.

References

1. FDA (1997) Food labeling: health claims; oats and coronary heart disease. Rules and Regulations, Federal Register 62: 3584–3601.
2. Kurtzweil P (1998) Staking a claim to good health. FDA and science stand behind health claims on foods. FDA Consum 32: 16-18, 21.
3. Day Li, Seymour RB, Pitts KF, Konczak I, Lundin L (2009) Incorporation of functional ingredients into foods. Trends Food Sci Technol 20: 388-395.
4. Scholan I (2007) Functional Beverages-- where next? Innovation in functional beverages market is set to continue. Int Food Ingredients.
5. Menrad K (2003) Market and marketing of functional food in Europe. J Food Eng 56: 181-188.
6. Woodward JR, Fincher GB, Stone BA (1983) Water-soluble (1→3) (1→4)-β-D-glucans from barley (*Hordeum vulgare*) endosperm II. Fine structure. Carbohydr Polym 3: 207-215.
7. Wood PJ, Weisz J, Blackwell BA (1994) Structural studies of (1→3) (1→4)-β-D-glucans by 13C-nuclear magnetic resonance spectroscopy and by rapid analysis of cellulose-like regions using high-performance anion-exchange chromatography of oligosaccharides released by lichenase. Cereal Chem 71: 301-307.
8. Gardiner T (2000) Beta-glucan biological activities: A Review.
9. Klis FM, Mol P, Hellingwerf K, Brul S (2002) Dynamics of cell wall structure in *Saccharomyces cerevisiae*. FEMS Microbiol Rev 26: 239-256.
10. Dongowski G, Huth M, Gebhardt E, Flamme W (2002) Dietary fiber-rich barley products beneficially affect the intestinal tract of rats. J Nutr 132: 3704-3714.
11. Valle-Jones JC (1985) An open study of oat bran meal biscuits ('Lejfibre') in the treatment of constipation in the elderly. Curr Med Res Opin 9: 716-720.
12. Tungland BC (2003) Fructooligosaccharides and other fructans: structures and occurrence, production, regulatory aspects, food applications, and nutritional health significance. ACS Publications.
13. Jenkins AL, Jenkins DJ, Zdravkovic U, Würsch P, Vuksan V (2002) Depression of the glycemic index by high levels of beta-glucan fiber in two functional foods tested in type 2 diabetes. Eur J Clin Nutr 56: 622-628.
14. Ahmad A, Anjum FM, Zahoor T, Nawaz H (2009) Extraction of β-glucan from oat and its interaction with glucose and lipoprotein profile. Pak J Nut 8: 1486-1492.
15. Hallfrisch J, Scholfield DJ, Behall KM (2003) Physiological responses of men and women to barley and oat extracts (Nu-trimX). II. Comparison of glucose and insulin responses. Cereal Chem 80: 80-83.
16. Wang J, Rosell CM, Benedito de Barber C (2002) Effect of the addition of different fibres on wheat dough performance and bread quality. Food Chem 79: 221-226.
17. Dawkins NL, Nnanna IA (1995) Studies on oat gum [(1→3, 1→4)-β-D-glucan]: composition, molecular weight estimation and rheological properties. Food Hydrocoll 9: 1-7.
18. Burkus Z, Temelli F (2000) Stabilization of emulsions and foams using barley β-glucan. Food Res Int 33: 27-33.
19. Tudorica CM, Jones TER, Kuri V, Brennan CS (2004) The effects of refined barley β-glucan on the physico-structural properties of low-fat dairy products: curd yield, microstructure, texture and rheology. J Sci Food Agric 84: 1159-1169.

20. Temelli F (2001) Potential food applications of barley beta-glucan concentrate. Barley County, Alberta barley Commission.

21. Henry RJ (1987) Pentosan and (1→3), (1→4)-[beta]-Glucan concentrations in endosperm and wholegrain of wheat, barley, oats and rye. J Cereal Sci 6: 253-258.

22. Bhatty RS (1992) Beta-Glucan content and viscosities of barleys and their roller-milled flour and bran products. Cereal Chem 69: 469-471.

23. Oscarsson M, Andersson R, Salomonsson AC, Åman P (1996) Chemical composition of barley samples focusing on dietary fibre components. J Cereal Sci 24: 161-170.

24. Nilsson M, Åman P, Harkonen H, Hallmans G, Knudsen KEB, et al. (1997) Content of nutrients and lignans in roller milled fractions of rye. J Sci Food Agric 73: 143-148.

25. Ahmad A, Anjum FM (2010) Persepctive of β-glucan: Extraction and Utilization. VDM Verlag Publishers, Germany.

26. Zhang G, Junmei W, Jinxin C (2002) Analysis of β-glucan content in barley cultivars from different locations of China. Food Chem 79: 251-254.

27. Stuart I, Loi L, Fincher G (1988) Varietal and environmental variations in (1→3, 1→4)-β-glucan levels and (1→3, 1→4)-β-glucanase potential in barley: Relationships to malting quality. J Cereal Sci 7: 61-71.

28. Anker-Nilssen K, Færgestad E, Sahlstrom S, Uhlen AK (2006) Interaction between barley cultivars and growth temperature on starch degradation properties measured *in vitro*. Anim Feed Sci Technol 130: 3-22.

29. Brunner BR, Freed RD (1993) Oat grain beta-glucan content as affected by nitrogen level, location, and year. Crop Sci 34: 473-476.

30. Güler M (2003) Nitrogen and irrigation effects on β-glucan content of wheat grain. Acta Agriculturae Scandinavica, Section B - Soil & Plant Science 53: 156-160.

31. Hollmann J, Lindhauer MG (2005) Pilot-scale isolation of glucuronoarabinoxylans from wheat bran. Carbohydr Polym 59: 225-230.

32. Tosh SM, Brummer Y, Wood PJ, Wang Q, Weisz J (2004) Evaluation of structure in the formation of gels by structurally diverse (1→3)(1→4)-[beta]-glucans from four cereal and one lichen species. Carbohydr Polym 57: 249-259.

33. Inglett GE, Carriere CJ, Maneepun S, Tungtrakul P (2004) A soluble fibre gel produced from rice bran and barley flour as a fat replacer in Asian foods. Int J Food Sci Technol 39: 1-10.

34. Temelli F (1997) Extraction and Functional Properties of Barley β-Glucan as Affected by Temperature and pH. J Food Sci 62: 1194-1201.

35. Freimund S, Sauter M, Kappeli O, Dutler H (2003) A new non-degrading isolation process for 1, 3-β-d-glucan of high purity from baker's yeast *Saccharomyces cerevisiae*. Carbohydr Polym 54: 159-171.

36. Nguyen TH, Fleet GH, Rogers PL (1998) Composition of the cell walls of several yeast species. Appl Microbiol Biotechnol 50: 206-212.

37. Mizuno M, Kawakami S, Fujitake N (2003) Macrophages Stimulated by Polysaccharide Purified from Agaricus brasiliensis. Int J Medic Mush 5: 5-9.

38. Zhang M, Cheung PC, Ooi VE, Zhang L (2004) Evaluation of sulfated fungal beta-glucans from the sclerotium of Pleurotus tuber-regium as a potential water-soluble anti-viral agent. Carbohydr Res 339: 2297-2301.

39. Kodama N, Komuta K, Nanba H (2003) Effect of Maitake (*Grifola frondosa*) D-Fraction on the activation of NK cells in cancer patients. J Med Food 6: 371-377.

40. Chihara G (1993) Medical aspects of lentinan isolated from *Lentinus edodes* (Berk.) Sing. Mushroom Biology and Mushroom Products.

41. Carbonero ER, Gracher AHP, Smiderle FR, Rosado FR, Sassaki GL, et al. (2006) A β-glucan from the fruit bodies of edible mushrooms *Pleurotus eryngii* and *Pleurotus ostreatoroseus*. Carbohydr Polym 66: 252-257.

42. Lindequist U, Niedermeyer TH, Jülich WD (2005) The pharmacological potential of mushrooms. Evid Based Complement Alternat Med 2: 285-299.

43. Chakraborty I, Mondal S, Rout D, Islam SS (2006) A water-insoluble (1→3)-[beta]-d-glucan from the alkaline extract of an edible mushroom Termitomyces eurhizus. Carbohydr Res 341: 2990-2993.

44. Demirbas A (2005) [beta]-Glucan and mineral nutrient contents of cereals grown in Turkey. Food Chem 90: 773-777.

45. Blakeney AB, Flinn PC (2005) Determination of non-starch polysaccharides in cereal grains with near-infared reflectance spectroscopy. Mol Nutr Food Res 49: 546-550.

46. Carter JF (2005) Potential of Flaxseed and flaxseed oil in baked goods and other products in human nutrition. Cereal Food World 38: 753-759.

47. Gene H, Ozdemir M, Demirbas A (2001) Analysis of mixedlinked (1→3)(1→4)-b-D-glucans in cereal grains from Turkey. Food Chem 73: 221-224.

48. Hozova B, Kuniak L, Morvcikova P, Gajdosova A (2007) Determination of water insoluble β-D-glucan in the whole grain cereals and pseudocereals. Czech J Food Sci 25: 316-324.

49. Cui SW, Wang Q (2009) Cell wall polysaccharides in cereals: chemical structure and functional properties. Struct Chem 20: 291-297.

50. McIntosh GH (2001) Cereal foods, fibres and the prevention of cancers. Aust J Nutr Diet 58: 212-218.

51. Braaten JT, Wood PJ, Scott FW, Wolynetz MS, Lowe MK, et al. (1994) Oat beta-glucan reduces blood cholesterol concentration in hypercholesterolemic subjects. Eur J Clin Nutr 48: 465-474.

52. Ahmad A, Anjum FM, Zahoor T, Nawaz H, Dilshad SM (2012) Beta glucan: a valuable functional ingredient in foods. Crit Rev Food Sci Nutr 52: 201-212.

53. Anderson JW (1995) Dietary fibre, complex carbohydrate and coronary artery disease. Can J Cardiol 55G-62G.

54. Glore SR, Van Treeck D, Knehans AW, Guild M (1994) Soluble fiber and serum lipids: a literature review. J Am Diet Assoc 94: 425-436.

55. Davidson MH, Dugan LD, Burns JH, Bova J, Story K, et al. (1991) The hypocholesterolemic effects of beta-glucan in oatmeal and oat bran. A dose-controlled study. JAMA 265: 1833-1839.

56. Pomeroy S, Tupper R, Cehun-Aders M, Nestel P (2001) Oat β-glucan lowers total and LDL-cholesterol. Aust J Nutr Diet 58: 51-55.

57. Ahmad A, Anjum FM, Zahoor T, Nawaz H, Ahmed Z (2010) Extraction and characterization of beta-D-glucan from oat for industrial utilization. Int J Biol Macromol 46: 304-309.

58. Keenan JM, Goulson M, Shamliyan T, Knutson N, Kolberg L, et al. (2007) The effects of concentrated barley beta-glucan on blood lipids in a population of hypercholesterolaemic men and women. Br J Nutr 97: 1162-1168.

59. Amundsen ÅL, Haugum B, Andersson H (2003) Changes in serum cholesterol and sterol metabolites after intake of products enriched with an oat bran concentrate within a controlled diet. Food Nutr Res 47: 68-74.

60. Briel M, Ferreira-Gonzalez I, You JJ, Karanicolas PJ, Akl EA, et al. (2009) Association between change in high density lipoprotein cholesterol and cardiovascular disease morbidity and mortality: systematic review and meta-regression analysis. BMJ 338: b92.

61. Wang J, Rosell CM, Benedito de Barber C (2002) Effect of the addition of different fibres on wheat dough performance and bread quality. Food Chem 79: 221-226.

62. Monro JA (2002) Faecal bulking efficacy of Australasian breakfast cereals. Asia Pac J Clin Nutr 11: 176-185.

63. Volikakis P, Biliaderis CG, Vamvakas C, Zerfiridis GK (2004) Effects of a commercial oat-[beta]-glucan concentrate on the chemical, physico-chemical and sensory attributes of a low-fat white-brined cheese product. Food Res Int 37: 83-94.

64. Burkus Z, Temelli F (2005) Rheological properties of barley β-glucan. Carbohydr polym 59: 459-465.

65. Brennan CS (2005) Dietary fibre, glycaemic response, and diabetes. Mol Nutr Food Res 49: 560-570.

66. Jenkins DJ, Wolever TM, Taylor RH, Barker H, Fielden H, et al. (1981) Glycemic index of foods: a physiological basis for carbohydrate exchange. Am J Clin Nutr 34: 362-366.

67. American Diabetes Association (2000) Nutrition Recommendations and Principles for People with Diabetes Mellitus. Diabetes Care 23: S43-46.

68. Kabir M, Oppert JM, Vidal H, Bruzzo F, Fiquet C, et al. (2002) Four-week

low-glycemic index breakfast with a modest amount of soluble fibers in type 2 diabetic men. Metabolism 51: 819-826.

69. Kim H, Stote KS, Behall KM, Spears K, Vinyard B, et al. (2009) Glucose and insulin responses to whole grain breakfasts varying in soluble fiber, beta-glucan: a dose response study in obese women with increased risk for insulin resistance. Eur J Nutr 48: 170-175.

70. Poppitt SD, van Drunen JD, McGill AT, Mulvey TB, Leahy FE (2007) Supplementation of a high-carbohydrate breakfast with barley beta-glucan improves postprandial glycaemic response for meals but not beverages. Asia Pac J Clin Nutr 16: 16-24.

71. Warrand J (2006) Healthy polysaccharides. Food Technol Biotechnol 44: 355-370.

72. Schneeman BO (2002) Gastrointestinal physiology and functions. Br J Nutr 2: S159-163.

73. Wood PJ, Beer MU, Butler G (2000) Evaluation of role of concentration and molecular weight of oat beta-glucan in determining effect of viscosity on plasma glucose and insulin following an oral glucose load. Br J Nutr 84: 19-23.

74. Kahlon T, Chow FI (1997) Hypocholesterolemic effects of oat, rice, and barley dietary fibers and fractions. Cereal Foods World 42: 86-92.

75. Ooi VE, Liu F (2000) Immunomodulation and anti-cancer activity of polysaccharide-protein complexes. Curr Med Chem 7: 715-729.

76. Cheung NK, Modak S, Vickers A, Knuckles B (2002) Orally administered beta-glucans enhance anti-tumor effects of monoclonal antibodies. Cancer Immunol Immunother 51: 557-564.

77. Tomasik PJ, Tomasik P (2003) Probiotics and prebiotics. Cereal Chem 80: 113-117.

78. Irakli M, Biliaderis CG, Izydorczyk MS, Papadoyannis IN (2004) Isolation, structural features and rheological properties of water-extractable β-glucans from different Greek barley cultivars. J Sci Food Agric 84: 1170-1178.

79. Li W, Cui SW, Kakuda Y (2006) Extraction, fractionation, structural and physical characterization of wheat [beta]-d-glucans. Carbohydr Polym 63: 408-416.

80. Tejinder S, Bhupinder K, Harinder K (2000) Flow behavior and functional properties of barley and oat water soluble β-D-glucan rich extractions. Int J Food Prop 3: 259-274.

81. Konuklar G, Inglett G, Warner K, Carriere CJ (2004) Use of a [beta]-glucan hydrocolloidal suspension in the manufacture of low-fat Cheddar cheeses: textural properties by instrumental methods and sensory panels. Food Hydrocoll 18: 535-545.

82. Morgan KR, Ofman DJ (1998) Glucagel, A Gelling β-Glucan from Barley. Cereal Chem 75: 879-881.

83. Brennan C, Tudorica C, Kuri V (2002) Soluble and insoluble dietary fibres (non-starch polysaccharides) and their effects on food structure and nutrition. Leatherhead Food Ra Food Industry J 5: 261-272.

84. Yokoyama WH, Hudson CA, Knucles BE, Chiu MCM, Sayre RN, et al. (1997) Effect of barley β -glucan in durum wheat pasta on human glycemic response. Cereal Chem 74: 293-296.

85. Lazaridou A, Duta D, Papageorgiou M, Belc N, Biliaderis CG (2007) Effects of hydrocolloids on dough rheology and bread quality parameters in gluten-free formulations. J Food Eng 79: 1033-1047.

86. Cavallero A, Empilli S, Brighenti F, Stanca AM (2002) High (1→3, 1→4)-[beta]-Glucan Barley fractions in bread making and their effects on human glycemic response. J Cereal Sci 36: 59-66.

87. Izydorczyk MS, Dexter JE (2008) Barley β -glucans and arabinoxylans: Molecular structure, physicochemical properties, and uses in food products a Review. Food Res Int 41: 850-868.

88. Tiwari U, Cummins E (2009) Factors influencing β-glucan levels and molecular weight in cereal-based products. Cereal Chem 86: 290-301.

89. Brennan CS, Cleary LJ (2007) Utilisation Glucagel® in the [beta]-glucan enrichment of breads: a physicochemical and nutritional evaluation. Food Res Int 40: 291-296.

90. Dubois DK (1978) The practical applications of fiber materials in bread Production. Bakers Dig 52: 30-33.

91. Knuckles B, Yokoyama W, Chiu MM (1997) Molecular characterization of barley β-glucans by size-exclusion chromatography with multiple-angle laser light scattering and other detectors. Cereal Chem 74: 599-604.

92. Bekers M, Marauska M, Laukevics J, Grube M, Vigants A, et al. (2001) Oats and fat-free milk based functional food product. Food Biotechnol 15: 1-12.

93. Fernández-García E, McGregor JU, Traylor S (1998) The addition of oat fiber and natural alternative sweeteners in the manufacture of plain yogurt. J Dairy Sci 81: 655-663.

94. Kontula P, von Wright A, Mattila-Sandholm T (1998) Oat bran beta-gluco- and xylo-oligosaccharides as fermentative substrates for lactic acid bacteria. Int J Food Microbiol 45: 163-169.

95. Knuckles BE, Hudson CA, Chiu MM, Sayre RN (1991) Effect of β-glucan barley fractions in high-fiber bread and pasta. Cereal Food World 42: 94-100.

96. Gómez C, Navarro A, Manzanares P, Horta A, Carbonell JV (1997) Physical and structural properties of barley (1→3),(1→4)-β-d-glucan. Part II. Viscosity, chain stiffness and macromolecular dimensions. Carbohydr Polym 32: 17-22.

97. Beer MU, Wood PJ, Weisz J, Fillion N (1997) Effect of Cooking and Storage on the Amount and Molecular Weight of (1→3)(1→4)-β-d-Glucan extracted from oat products by an *in vitro* Digestion System 1. Cereal Chem 74: 705-709.

98. Morin L, Temelli F, McMullen L (2002) Physical and sensory characteristics of reduced-fat breakfast sausages formulated with barley β-glucan. J Food Sci 67: 2391-2396.

99. Morgan KR, Ofman DJ (1998). Glucagel, a gelling beta glucan from barley. Cereal Chem 75: 879-881.

100. Din A, Anjum FM, Zahoor T, Nawaz H (2009) Extraction and utilization of barley beta-glucan for the preparation of functional beverage. Int J Agri and Biol 11: 737-740.

101. Lyly M, Roininen K, Honkapaa K, Poutanen K, Lahteenmaki L (2007) Factors influencing consumers' willingness to use beverages and ready-to-eat frozen soups containing oat [beta]-glucan in Finland, France and Sweden. Food Qual Prefer 18: 242-255.

102. Giese JH (1992) Hitting the spot: beverages and beverage technology. Food Technol 46:70-72, 74-75, 78-80.

103. Thammakiti S, Suphantharika M, Phaesuwan T, Verduyn C (2004) Preparation of spent brewer's yeast β-glucans for potential applications in the food industry. Int J Food Sci Tech 39: 21-29.

104. Ahmad A, Anjum FM, Zahoor T, Nawaz H (2008) Effect of barley β-glucan on sensory characteristics of bread. Pak J Agric Sci 45: 88-94.

105. Ahmad A, Anjum FM, Zahoor T, Nawaz H, Din A (2009) Physicochemical and functional properties of barley β-glucan as affected by different extraction procedures. Int J Food Sci Tech 44: 181-87.

106. Novak M, Vetvicka V (2008) Beta-glucans, history, and the present: immunomodulatory aspects and mechanisms of action. J Immunotoxicol 5: 47-57.

107. Brown GD (2006) Dectin-1: a signalling non-TLR pattern-recognition receptor. Nat Rev Immunol 6: 33-43.

108. Brown GD, Gordon S (2001) Immune recognition. A new receptor for beta-glucans. Nature 413: 36-37.

109. Bohn JA, BeMiller JN (1995) (1→3)-[beta]-D-Glucans as biological response modifiers: a review of structure-functional activity relationships. Carbohydr Polym 28: 3-14.

110. Maeda YY, Watanabe ST, Chihara C, Rokutanda M (1988) Denaturation and renaturation of a beta-1,6;1,3-glucan, lentinan, associated with expression of T-cell-mediated responses. Cancer Res 48: 671-675.

111. Soltes L, Alfoldi J, Sandula J (1993) HPLC and ^{13}C-NMR study of carboxymethyl-β-(1→6)-D-gluco-β-(1→3)-D-glucan derived from *saccharomyces cerevisiae*. J Applied Polymer Sci 48: 1313-1319.

112. Williams DL, McNamee RB, Jones EL, Pretus HA, Ensley HE, et al. (1991) A method for the solubilization of a (1→3)-β-D-glucan isolated from *Saccharomyces cerevisiae*. Carbohydr Res 219: 203-213.

113. Williams DL, Pretus HA, McNamee RB, Jones EL, Ensley HE, et al. (1992) Development of a water-soluble, sulfated (1→3)-[beta]-d-glucan biological response modifier derived from *Saccharomyces cerevisiae*. Carbohydr Res 235: 247-257.

114. Sandula J, Kogan G, Kacuráková M, Machová E (1999) Microbial (1→3)-β-d-glucans, their preparation, physico-chemical characterization and immunomodulatory activity. Carbohydr Polym 38: 247-253.

115. Kogan G, Masler L, Sandula J, Navarová J, Trnovec T (1989) Recent results on the structure and immunomodulating activities of yeast glucan. Biomedical and biotechnological advances in industrial polysaccharides. New York, USA.

116. Abel G, Czop JK (1992) Stimulation of human monocyte beta-glucan receptors by glucan particles induces production of TNF-alpha and IL-1 beta. Int J Immunopharmacol 14: 1363-1373.

117. Olson EJ, Standing JE, Griego-Harper N, Hoffman OA, Limper AH (1996) Fungal beta-glucan interacts with vitronectin and stimulates tumor necrosis factor alpha release from macrophages. Infect Immun 64: 3548-3554.

118. Vassallo R, Kottom TJ, Standing JE, Limper AH (2001) Vitronectin and fibronectin function as glucan binding proteins augmenting macrophage responses to Pneumocystis carinii. Am J Respir Cell Mol Biol 25: 203-211.

119. Pelizon AC, Kaneno R, Soares AM, Meira DA, Sartori A (2005) Immunomodulatory activities associated with beta-glucan derived from *Saccharomyces cerevisiae*. Physiol Res 54: 557-564.

120. Engstad CS, Engstad RE, Olsen JO, Osterud B (2002) The effect of soluble beta-1,3-glucan and lipopolysaccharide on cytokine production and coagulation activation in whole blood. Int Immunopharmacol 2: 1585-1597.

121. Vetvicka V, Thornton BP, Ross GD (1996) Soluble beta-glucan polysaccharide binding to the lectin site of neutrophil or natural killer cell complement receptor type 3 (CD11b/CD18) generates a primed state of the receptor capable of mediating cytotoxicity of iC3b-opsonized target cells. J Clin Invest 98: 50-61.

122. Takeda K, Okumura K (2004) CAM and NK Cells. Evid Based Complement Alternat Med 1: 17-27.