

β-Glucan and Functionality: A Review

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Abstract

Beta-glucans polysaccharide in nature found in the bran of cereal grains (barley and oats and to a much lesser degree in rye and wheat, in amounts of about 7%, 5%, 2% and less than 1%, respectively), the cell wall of baker's yeast, certain types of fungi, and many kinds of mushrooms. Beta-glucans promote health in a number of important ways. Beta-glucans have been studied for their hypocholesterolemic effects; these mechanisms include: reducing the intestinal absorption of cholesterol and bile acids by binding to glucans; shifting the liver from cholesterol syntheses to bile acid production; and fermentation by intestinal bacteria to short-chain fatty acids, which are absorbed and inhibit hepatic cholesterol syntheses. Several studies have also shown that oat beta-glucans blunt the glycemic and insulin response. The differences between soluble and insoluble beta-glucans are significant in regards to application, mode of action, and overall biological activity. Moreover, beta-1,3-glucans improve the body's immune system defense against foreign invaders by enhancing the ability of macrophages, neutrophils and natural killer cells to respond to and fight a wide range of challenges such as bacteria, viruses, fungi, and parasites.

Keywords: Beta-Glucans; Hypocholesterolemic; Cholesterol and Macrophages; Neutrophils

Introduction

Beta glucan is a polymer of D-glucose linked with glycosidic bonds at β (1 → 3), β (1 → 4), β (1 → 6) and is typically found in the endosperm cell wall in oats, barley. Beta glucan is commercially derived from oats, barley, mushrooms and some microorganisms. Beta glucans derived from cereals are polymers of D-glucose with β (1 → 3) and β (1 → 4) linkages. Beta glucan constitutes 1 % of wheat grains, 3-7% of oats and 5 - 11% of barley [1]. According to the type of glycosidic bond they are classified into alpha and beta glucans. Dextran, glycogen, pullulan and starch are some examples for alpha glucans. Cellulose, curdlan, laminarins etc are some examples for beta glucans. The most active form of beta-(1→3)-D glucans are those that contain 1, 6 side-chains branching off from the longer beta (1→3) glucan backbone. These are referred to as beta (1→3)/ (1→ 6) glucan. In some cases, proteins linked glucans are mainly (1→4) and (1→6) linked but in beta glucan mainly (1→3), to the beta (1→ 3) glucan backbones may also be involved in imparting therapeutic activity. 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. The β -glucans are recognized as the effective ingredients in fungal and certain bacterial cell walls also. About half the mass of the fungal cell wall consists of β -glucans. Natural products containing fungal β -glucans have been consumed for probably thousands of years, especially for their role in improving general health. In recent years, β -glucans have been noted as potent stimulators of mammalian immune system. Among the products with B-glucans, Zymosan is a very potent immune stimulator that has been widely used in research. It is a mixture of proteins, lipids and polysaccharides isolated from the cell wall of *Saccharomyces cerevisiae*. Structurally, they have a linear backbone of D-glucose in β -1,3 linkage with side branches in β -1,6 linkage at various intervals. The presence of side branches in the intermediate layer of the cell wall imparts shape and rigidity to the cell. The molecular structure also depends also on the source and method of isolation with differences in the distribution and length of side chains.

Some naturally occurring glucans are of particular clinical interest. The noteworthy natural β glucans are Lentinans, Schizophyllan, PSK (Krestin). Lentinan is mushroom extracted and has a triple helix structure with five (1→3) β glucose linear residues and two (1→6) β glucopyranoside side branches. Schizophyllan, from the mushroom of *Schizophyllum commune*, has β glucopyranosyl (1→6) linkage every third or fourth interval between the 1,3 units. It also has a triple-helix structure. PSK (krestin) is composed of 25.38% protein residues and is a (1→4)β glucan with (1→6) β glucopyranosidic lateral chains, obtained from mushroom *Coriolus versicolus*, it has a molecular weight of 94 kDa, the least among the natural β glucan types. Beta-glucans are a major component of the soluble dietary fibre and they influence the nutritional values and functional properties of food. Recently, several studies have revealed the benefits of including β-glucans into the diet to the human health, such as cholesterol diminution in blood, and reduction of risk of cancer, coronary heart disease, and diabetes.

Health effects of β-glucan

Russo and Yanong [2], reported that beta-glucans and nucleotides can help improve disease resistance in fish. However, their effectiveness may be depends upon confounding factors (genetics, nutrition quality, stress, water temperature, and handling).

Chen and Seviour [3], suggested that β-glucans are effective in treating diseases like cancer, a range of microbial infections, hypercholesterolaemia, and diabetes. Their mechanisms of action involve them being recognized as non-self molecules, so the immune system is stimulated by their presence. Several receptors have been identified, which include: dectin-1, located on macrophages which mediates β-glucan activation of phagocytosis and production of cytokines, a response coordinated by the toll-like receptor-2. Activated complement receptors on natural killer cells, neutrophils, and lymphocytes, may also be associated with tumour cytotoxicity. Two other receptors, scavenger and lactosylceramide, bind beta-glucans and mediate a series of signal pathways leading to immunological activation. Structurally different β -glucans appear to have different affinities toward these receptors and thus generate markedly different host responses.

Boshy, *et al.* [4] investigated that the β-glucans was able to enhance the non-specific immunity of the Nile tilapia (*Oreochromis niloticus*) immune compromised with aflatoxin B1. The immune stimulant beta-1→3 glucan was fed at 0.1% and/or aflatoxin B1 at 200 µg crude/Kg feed for 21 days in Nile tilapia. Dietary supplementation aflatoxin B1 treated group showed significant reduction in non-specific immunity as reduced superoxide anion production of blood phagocytes, serum lysozyme, serum bactericidal activity, and neutrophils glass adhesion and macrophage phagocytic indices. Feeding of beta-1→ 3 glucans to healthy fish raised the non-specific immunity and protection against bacterial infection compared with the control.

Rop, *et al.* [5] reported that beta-glucans had marked immunity-stimulating effects in both humans and animals, have been found in numerous fungal species. Beta glucans appear to be promising for aiding in the cure of timorous diseases, reduce cholesterol levels in blood and positively influence the metabolism of fats and sugars within the human body. They contribute to improved resistance against allergies by increasing the numbers of Th1 lymphocytes in blood. In terms of biological activity, β -1,3-D-glucans and β -1,6-D-glucans, which are contained in Oyster, Shiitake, and Split Gill mushrooms, as well as other basidiomycetes, are considered to be the most effective.

Andersson [6] observed cholesterol-lowering properties of oats, due to its contents of soluble fibers, beta-glucans, whereas effects on atherogenesis are less well elucidated. Oats also contains components with reported antioxidant and anti-inflammatory effects that may affect atherogenesis. Also examined effects of oat bran on plasma cholesterol, markers of inflammation and development of atherosclerosis in LDL-receptor-deficient mice.

Salim, *et al.* [7] evaluate the effect of feeding prebiotic (Beta-glucan) on leukocytes, some biochemical blood parameters and immune response in normal and Salmonella infected chicks. Beta-glucan was used as Prebiotic. Results of prebiotic supplementation revealed significant leukocytosis and lymphocytosis, hyperproteinemia, hyperglobinemia, and significant decrease in triglycerides, total cholesterol, and glucose concentration with no significant change in the values of uric acid and creatinine concentration, also significant increase in phagocytic activity and phagocytic index were observed. Prebiotic did not induce any harmful effect on liver or kidney and it decrease

serum lipid. Prebiotic can be considered as an immunopotentiators due to stimulation of immune system and it has the ability to reduce the adverse effect of *Salmonella typhimurium* infection in broiler chicks.

Uslu and Bagriacik [8], investigated and compared adjuvant effects of soluble β-glucans from barley and *Saccharomyces cerevisiae* in induction of antigen specific humoral immune responses. Mice were immunized with conalbumin at a relatively low concentration in the presence of beta glucans. Anti-conalbumin antibodies in the serum of immunized and control mice were quantified by enzyme linked immune sorbent assay. At high doses, both of glucans increased effectively levels of circulating IgM and IgG antibodies which were specific for conalbumin. They found that antigen (conalbumin) specific antibody levels enhanced by β-glucan from *Saccharomyces cerevisiae* were always higher than those of the glucan from barley and concluded that (1→3),(1→6)- β-D-glucan from yeast cell wall might have superior immunostimulant activity in induction of antigen specific humoral immune responses over (1→3),(1→4)- β-D-glucan from barley.

Medeiros, *et al.* [9] investigated the effects of (1→3)-β-glucan on venous ulcer healing in humans and found that this glucan is a potential natural biological response modifier in wound healing. This water-insoluble glucan was isolated from the baker's yeast *Saccharomyces cerevisiae*. The effects of the glucan on wound healing were assessed in human venous ulcers by histopathological analysis after 30 days of topical treatment. (1→3)-β-glucan enhanced ulcer healing and increased epithelial hyperplasia, as well as increased inflammatory cells, angiogenesis and fibroblast proliferation.

Vatandoust [10], studied the effectiveness of β-glucan by controlling depolymerization of β-glucan in baked products to confer health benefits and demonstrated that endogenous β-glucanase in wheat kernels are responsible for the depolymerization of β-glucans. The results demonstrated that enzymes with β-glucanase activity are concentrated primarily in the outer layer of wheat kernels. Also genotype, environmental conditions and agronomic practice all had significant effects on the β-glucanase activity in wheat flours and poor harvesting conditions can significantly increase β-glucanase activity level in wheat. The kinetics results demonstrated that moisture content, incubation time and levels of endogenous β-glucanase activity of the system had significant impact on the final molecular weight of β-glucan in the dough.

Shaki and Pourahmad [11], examined the ability of the two antioxidants, beta-glucan and butylated hydroxyl toluene (BHT), to prevent uranyl acetate induced mitochondrial dysfunction using rat isolated kidney mitochondria. Beta-glucan (150nM) and BHT (20 nM) attenuated uranyl acetate induced mitochondrial reactive oxygen species (ROS) formation, lipid peroxidation and glutathione oxidation. Beta-glucan and butylated hydroxy toluene also prevented the loss of mitochondrial membrane potential and mitochondrial swelling following the uranyl acetate treatment in isolated mitochondria. Also showed that beta-glucan and butylated hydroxy toluene prevented uranyl acetate induced mitochondrial outer membrane damage as well as release of cytochrome C from mitochondria. Uranyl acetate also decreased the ATP production in isolated mitochondria significantly inhibited with beta-glucan and butylated hydroxy toluene pre-treatment. They reported that beta-glucan may be mitochondria-targeted antioxidant and suggested this compound as a possible drug candidate for prophylaxis and treatment against depleted uranium induced nephrotoxicity.

Physical and chemical characteristics of β-glucan

Lia, *et al.* [12] studied the effect of β-glucan on the excretion of bile acids using breads baked with oat bran, oat bran with β-glucanase, barley or wheat in the diet of ileostomy subjects. They showed that the excretion of bile acids was 53% higher with the oat bran bread than with the bread containing oat bran and β-glucanase, and also significantly higher than with barley and wheat bread. The excretion of cholesterol was higher for barley bread than for wheat or oat bran-β-glucanase bread.

Lily [13], studied the effect of concentration and molecular weight of two oat and one barley β -glucan preparation on the perceived sensory quality of a ready-to-eat soup prototype before and after freezing. Nine soups containing 0.25 - 2.0g β -glucan/100g soup and one reference soup thickened with starch were profiled by a sensory panel, viscosity and molecular weight of β -glucan was analysed. Freezing had no notable effects on the sensory quality of the soups. At the same concentration, soups made with the bran-type preparation were

more viscous and had higher perceived thickness than soups made with processed, low molecular weight preparations. Barley soups had mainly higher flavour intensities than oat soups. Good correlations were obtained between sensory texture attributes, viscosity and moderate correlations between flavour attributes and viscosity. Technologically, β-glucans are feasible thickening agent alternatives in soups.

Vadnerkar [14], studied to quantify resistant starch, beta-glucans, and fructo oligosaccharides in Indian and Canadian wheat varieties and in chapatias made from these. Flours and chapatias (freeze-dried, pulverized) were assayed for beta-glucans, fructo oligosaccharides, resistant starch and simple sugars (glucose/sucrose). Resistant starch content of flours ranged from 7.1g/100g to 12.6g/100g, but decreased when made into chapatias, (< 1g/100g), and decreased further with soy flour addition. Beta-glucans content in flours ranged from 0.8g/100g to 1.4g/100g, while fructooligosaccharides content ranged from 1.3g/100g to 2.3g/100g. Minimal changes were observed in beta-glucans and fructooligosaccharides content when made into chapatias. Simple sugars were minimal in flours and chapatias. WAI of wheat flour was increased with addition of soy bean flour. Addition of up to 30 % soybean flour elevated the sensory acceptability of chapatias. While there is a decrease in resistant starch with chapati making, the levels of beta-glucans and fructooligosaccharides are largely unchanged with processing.

Johansson [15], studied the structures, methods of hydrolysis of (1→3),(1→4)-β-D-glucans of oat bran, whole-grain oats and barley and processed foods. The isolated soluble β-glucans of oat bran and whole-grain oats and barley were hydrolysed with lichenase, an enzyme specific for (1→3), (1→4)-β-D-β-glucans. The main products were 3-O-β-cellobiosyl-D-glucose and 3-O-β-celotriosyl-D-glucose, the oligosaccharides which have a degree of polymerisation denoted by DP3 and DP4. Small differences were detected between soluble and insoluble β-glucans and also between β-glucans of oats and barley. These differences can only be seen in the DP3:DP4 ratio which was higher for barley than for oat and also higher for insoluble than for soluble β-glucan. A greater proportion of barley β-glucan remained insoluble than of oat β-glucan. Drying decreased the extractability for bread and fermentate but increased it for porridge. The viscosity of barley β-glucan was slightly higher than that of oat β-glucan.

Choo [16], incorporated the banana flour and oat β-glucan in noodles. The effects of adding increasing level (20% to 50%) of banana flour and 10% oat β-glucan on the physical, chemical, sensory and shelf-life properties of noodles were investigated. The replacement of wheat flour with increasing level of banana flour and additional of 10% oat β-glucan resulted in significantly higher ($p < 0.05$) in proximate parameters (moisture, protein, crude fibre, ash, and fat content), total dietary fibre (TDF), resistant starch (RS) and some essential minerals. Noodles incorporated with increasing level of banana flour contained higher amylopectin and noodles with additional of 10% oat β-glucan showed greater water holding capacity and thus produced less firm but stickier texture noodles. Incorporation of 10% oat β-glucan and the boiling step increased the lightness (L^*) of noodles. Noodle incorporated with 30% banana flour and with added oat β-glucan showed greatest antioxidant properties. Noodle added with oat β-glucan showed more porous microstructure than noodle without oat β-glucan.

Piotrowska, *et al.* [17] aimed at determining the possibility of beta-glucan from spent brewer's yeast addition to yoghurt. Analyses were conducted to determine the influence of beta-glucan addition on sensory characteristics and structure stability of yogurt. And reported the sensorially perceived consistency attributes (thickness and smoothness) and flavour attributes (yoghurt, acid, bitter and "other") were significantly affected by beta-glucan content. The addition of beta-glucan influenced also the structure stability of yoghurts. Up to 0.3% addition of beta-glucan enabled maintaining the same sensory quality and structure stability of natural yoghurts as compared to the control sample (without beta-glucan).

Han, *et al.* [18] studied the solubilization of water-insoluble β-glucan isolated from *Ganoderma lucidum*. The fungal β-D-glucan is a biological response modifier (BRM), but a major obstacle to the clinical utilization of β-glucan BRMs is their relative lack of solubility in aqueous media. Water insoluble fungal glucans extracted by alkali from the mycelia of *Ganoderma lucidum* were sulfated to yield their corresponding water-soluble derivatives. Insoluble glucan is dissolved in methyl sulfoxide and urea, and is partially sulfated with sulfuric acid. The sulfated glucan (SGL) yield prepared from insoluble glucan (IGL) was 85%, the sulfation degree of SGL was about 14.9%, and the solubility of SGL was above 95% in water. The monosugar SGL content was 34.9% alpha-glucose and 35.9% beta-glucose.

Benito, *et al.* [19] analyzed various operating parameters on the extraction of β-glucans from different varieties of barley in batch extractors, with a reference experiment, in order to check the influence of temperature, pH, time, solvent and flour:solvent ratio. Time and temperature showed to have a strongly marked influence: the higher temperature, the higher extraction rate. Higher temperatures led to improve the extraction yield, increasing the amount of starch co-extracted. Extraction time was a critical factor up to 3 hours. Longer times did not increase the amount extracted, it was observed an important decrease on the β-glucan solubility, greater the higher concentration of alcohol employed and the longer carbon chain. Finally, a extraction yield of 40-50% was obtained when operating at solvent:flour ratio from 7 to 12, at 55°C, in almost all range of pH, when lasting the extraction process more than 2,5 hours.

Liu, *et al.* [20] experimented on oat lines with high (6.2 - 7.2%), medium (5.5 - 5.9%), and low (4.4 - 5.3%) β -glucan concentrations for contributions of β -glucan, starch, protein, and their interactions, to pasting properties of oat flours by using a Rapid Visco Analyser (RVA). Significant correlations ($P < 0.05$) between β -glucan concentration and pasting parameters of oat slurries were obtained under autolysis without 1hr incubation, inhibition, and amylolysis. The relative decrease of viscosity after enzymatic hydrolysis of β -glucan correlated with β-glucan concentration ($P < 0.05$). The viscosity decreased by hydrolysis of protein was much greater than the actual viscosity remaining after hydrolysis of both β-glucan and starch, reconfirming the importance of interactions between protein and other oat components to pasting.

Liu and White [21], illustrated that concentration, peak molecular weight, ratio of DP3/DP4, amount of DP ≤ 5, and ratio of β-(1→4)/β-(1→3) linkages of β-glucans impacted the pasting properties of oat-flour slurries. They found that the molecular-structural characteristics of β-glucans impact on viscosity, and not just their concentrations and viscosity measurements may predict potential health benefits and sensory quality in foods. These results would also help plant breeders in developing oat lines with specific structures and the related targeted characteristics, such as high viscosities, for use in nutrition, high-quality oat-based food products.

Liu, *et al.* [22] studied the effect of steaming and flaking of oats on β-glucan structural-molecular characteristics, and oat-paste viscosities and in vitro bile acid binding. The steaming and flaking of oat groats could decrease the viscosities of oat-flour slurries while increasing the in vitro bile acid binding capacity of oat-flour slurries. The β-glucan molecular weight in oat flakes was less than in oat groats. After processing, the β-glucan DP3/DP4 ratio increased; whereas the amount of DP ≤ 5 and the β-(1→4)/β-(1→3) linkage ratio decreased. The structural-molecular changes of β-glucans during processing might explain the decreased viscosities and increased bile acid binding of oat slurries made from processed flakes.

Bangar [23], studied the effects of oat beta glucan on the stability and textural properties of beta glucan fortified milk beverage. The beta glucan fortified milk was made in one stage and two stages in a jacketed kettle. Stability and texture of the product can be described as a phase separation and viscosity of the beta glucan fortified milk. A significant difference ($p < 0.05$) in viscosity between the beta glucan samples made using two protocols was observed. However, within each protocol no significant difference between texture from day one and day six ($p > 0.05$) was observed.

Lathia [24], determined the influence of varying levels of beta-glucan in barley flour on selected properties of a model baked product. Batter rheology, pasting profiles of the barley flours and viscoelastic properties and firmness of the baked products was monitored for changes occurring due to varying β-glucan levels in barley flour and removal of sugar. Water absorption index was found to be significantly higher for high β-glucan barley flour. Low beta-glucan dough showed a lower biaxial extensional viscosity compared to the high beta-glucan dough, which indicates that the level of beta-glucan present in the barley flour has an impact on the dough viscosity.

Havrlentova, *et al.* [25] presented a brief review on the positive effects of β-glucans on the human's health. The structure, occurrence, sources, and positive physiological effects of β-glucans on the cardiovascular system but also their antibacterial, antitumoral, immunomodulant, and radioprotective properties. β-glucans exploitation as functional ingredients in food, cosmetic, and pharmaceutical industries and as food additives on the basis of cereal fibres and cereal β glucans.

Katongole [26], studied a protocol for the concentration of β-glucan, based on protein-polysaccharide incompatibility and extract obtained was utilized in beverages with increased β-glucan content on perceived satiety and blood glucose, at different fibre concentrations. Twenty nine healthy adults participated in this study. 5 beverage pre-loads, containing between 0 - 2.5g of β-glucan in 500 mL of the sample, were ingested 120 min before the given meal. Results showed a trend towards a decrease in appetite scores with increasing β-glucan content of the beverages, as well as differences in the blood glucose readings, though these were not significant, and could not solely be attributed to β-glucan content due to differences in beverage composition.

Sharafbafi [27], investigated macroscopic phase separation of milk proteins and high molecular weight oat beta-glucan. Phase behaviour diagram was constructed showing the beta-glucan and milk protein concentrations limits which cause phase separation at constant ionic and serum composition of the medium. Beta-glucan showed thermodynamic incompatibility with milk proteins (casein micelles) at concentrations lower than required for its health benefits (< 0.2%). Different structures (spherical or bi-continuous) were formed upon mixing in mixtures located higher than the binodal curve on the phase separation diagram. Spherical droplets rich in protein formed at high beta-glucan concentrations while spherical droplets rich in beta-glucan formed at high protein concentration. Rheological properties of these mixtures were mainly dependent on the high viscosity developed by beta-glucan in the serum, development of different structures increased the viscosity in the phase separating mixtures. The phase separated domains form due to an imbalance in the density of protein and polysaccharide dispersed evenly in solution. The attractive forces between casein micelles in close proximity of each other result in depletion of beta-glucan from between them, and phase separation.

Jonkova and Surleva [28], studied the influence of β-glucans on wort and beer viscosities, as well as beer quality. Also investigated production of wort from malt at different degree of cytolitic modification and estimation of the effect of exogenous β-glucanases addition during wort fermentation. β-Glucans content in poorly and well modified malt was 1000 mg L⁻¹ and 384 mg L⁻¹, respectively. The addition of enzymatic preparation with β-glucanases activity during the fermentation of wort, obtained from poorly modified malt, resulted in decreasing of beer viscosity by 5 – 40 % and decreasing of β-glucan content by more than 90%.

Nikoofar, *et al.* [29] studied oat beta glucan fiber in amount of 0.5, 1, 1.5 and 2 % (w/w) in production of non-fat yoghurts and compared manufactured samples of beta glucans effect yoghurt characteristics with non-fat and full fat yoghurts without beta glucan. Tests for comparison were consists of measurement of acidity, syneresis, color, texture tests (compression test, stress- relaxation test, texture profile analysis (TPA) test). Results of these tests showed that the acidity of samples containing beta glucan were higher due to the ability of beta glucan to increase the activity of acid producing bacteria's in fermentation. The syneresis of samples containing beta glucan were increasing due to the interaction of beta glucan polysaccharide with milk casein. Colors of samples containing beta glucan were darker than testifiers.

Texture tests showed that samples containing beta glucan had firmer and stickier texture in comparison with samples without beta glucan. In general, samples containing beta glucan had a firm and creamy texture.

Conclusion

Beta glucans from the bran of cereal grains (barley and oats and to a much lesser degree in rye and wheat, which show marked immunity-stimulating effects in both humans and animals, have been found in numerous fungal species. Based on recent findings, they appear to be promising for aiding in the cure of tumorous diseases. They help reduce cholesterol levels in blood and positively influence the metabolism of fats and sugars within the human body. They contribute to improved resistance against allergies by increasing the numbers of Th1 lymphocytes in blood. beta-1,3-glucans improve the body's immune system defense against foreign invaders by enhancing the ability of macrophages, neutrophils and natural killer cells to respond to and fight a wide range of challenges such as bacteria, viruses, fungi, and parasites.

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