The Functional Aspects of Beta Glucan for Dairy Industry

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Beta glucan (*β*-glucan), an important functional ingredient, has gained renewed interest from the food industry due to its health beneficiary compounds beyond basic nutrition. This soluble fiber, with high water-holding capacity and gelling, thickening, stabilizing and emulsification properties, is readily found in the cell walls of cereal grains (i.e. barley and oats), algae, bacteria and fungi. In scientific literature, beta-glucan has been documented for playing beneficiary role in insuline resistance, hypertension, and obesity; reduction of serum cholesterol levels; helping the production of short chain fatty acids and forming highly viscous solutions that promote the growth of beneficial gut microflora, and consequently, lowering the risk of cancer. In dairy products *β*-glucan is being widely used either to improve microstructure and rheological properties or enhance their health properties such as calorie-reduction and cholesterol-lowering. The objective of the present paper is to explore the role of *β*-glucans as a source of dietary fiber supplementation, their potential uses in dairy applications and development of new nutraceutical products.

Keywords: health benefits; *beta*-glucan; fiber; functional dairy foods

1. Introduction

Food industry aims to develop functional foods and ingredients with regard to the consumers' attitudes and behavior towards healthy and nutritous foods. *β*-glucans are commonly referred as dietary fibre. A dietary fibre, non-starchy carbohydrates, can be defined as the parts of plants such as cereals, vegetables, fruits, and nuts which are not digested within the small intestine since mammals do not produce enzymes capable to hydrolyze them into constituent monomers [1].

Based on their simulated intestinal solubility, dietary fibres are classified as either soluble or insoluble. Soluble fibres include pectins, beta-glucans, galactomanan gums, and a large range of non-digestible oligosaccharides i.e. inulin; insoluble fibres include lignin, cellulose, and hemicelluloses [2]. Dietary fibre is a non-nutrient as it reaches the colon intact and contributes no calories to the diet. In the colon, it is fermented by the beneficiary bacteria, and metabolized to short chain fatty acids (SCFAs) with the release of energy that promotes the growth of gut microbiota, acting as prebiotic [3-5].

2. Sources of *β*-glucans

2.1 Structure and functional properties of *β*-glucans

Glucans are non-starch polysaccharides commonly present in living organisms. They are polymers built of monosaccharides linked by alfa- and beta-type glycosidic bonds. Glucans have complex chemical structure and perform varied physicochemical properties. They can be divided into four main groups i) branched *β*-(1,3) glucans with high molecular mass (pleuran, lentinan, grifolanand schizophyllan), ii) *β*-glucans with lower molecular mass (e.g. carboxymethyl glucan), iii) glucans with small molecule (e.g. zymosan) and iv) α-glucans [6,7].

β-glucans are natural components of cell walls of plants, yeast, algae, bacteria and mushrooms, consisting of a *β*-(1,3)-linked D-glucopyranosyl backbone to which either linked *β*-(1,6) or *β*-(1,4) side chains of varying distribution and length (Fig. 1-2). Cereal (e.g., barley and oats) and bacterial *β*-glucans are primarily linear with large regions of *β*-(1,4) linkages separating shorter stretches of *β*-(1,3) structures. Mushroom *β*-glucans have short *β*-(1,6)-linked branches coming from the *β*-(1,3) backbone, while those of yeast have *β*-(1,6) branches that are further elaborated with additional *β*-(1,3) regions (Table 1) [8,9].

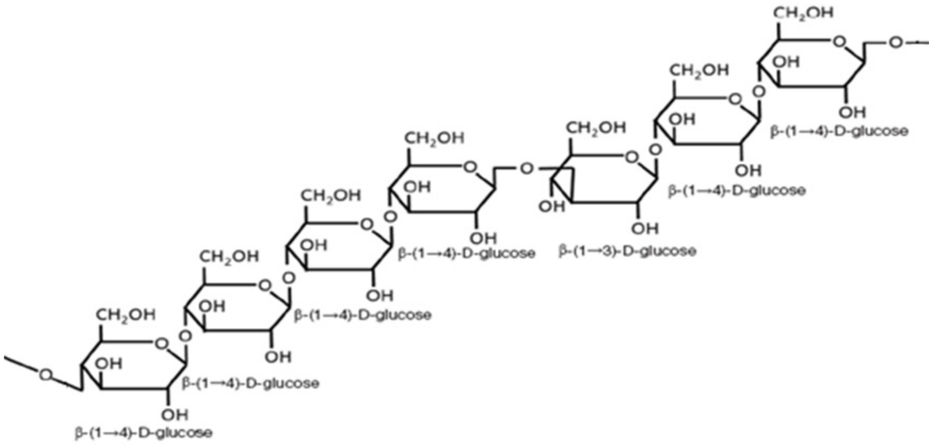


Fig. 1 Structure of *β*–glucans in cereals; *β*-(1,3) linear chain with *β*-(1,4) branch link bonds.

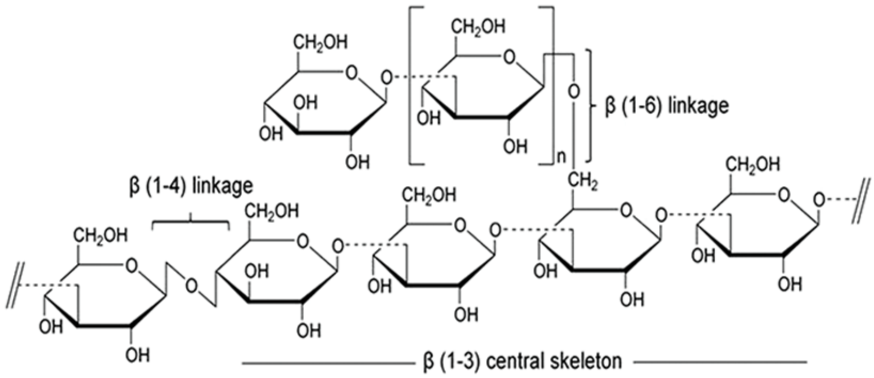


Fig. 2 Structure of *β*–glucans in yeasts; *β*-(1,3) linear chain with *β*-(1,6) branch link bonds.

The extraction conditions, molecular weight of *β*-glucans, degree of polymerization (DP) are responsible for their specific physical properties and characteristics, and determine their rheological properties and food applications [9-12].

Table 1 Beta-glucan types of different organisms with a schematic structure [11].

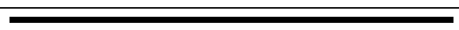
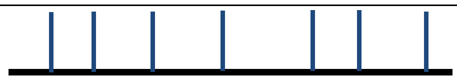
Organism	Structure	Description
Bacterial		Linear *β*-(1,3) glucan; i.e. curdlan
Yeast		Long chain *β*-(1,3) glucan with *β*-(1,6) branching; long spaces within branches; i.e. betafectini™, WGP *β*-glucan
Mushroom		Short chain *β*-(1,3) glucan with *β*-(1,6)branches; short spaces within branches; i.e. schizophyllan
Cereal		Linear *β*-(1,3)/ *β*-(1,4) glucan; i.e. oat, barley, rye

Table 2 Commonly used β-glucans [5,7,9,12]

Name	Source	Source type	Structure
Barley, oat, wheat, rye, rice		Cereal	β-(1,3)/β-(1,4) mixed linkage, unbranched
Curdlan	*Alcaligenes faecalis* *Agrobacterium radiobacter*	Gr (-) bacteria	*B*-(1,3) unbranched/ linear
Azorhizobium caulinodans	*A. caulinodans*	Gr (-) bacteria	β-(1,3)/β-(1,6) cyclic
Xanthan	*Xanthomonas campestris*	Gr (-) bacteria	β-(1,3)/ β-(1,4)/β-(1,2) side-chain-branched
Streptococcus pneumoniae	*Str. pneumoniae*	Gr (+) bacteria	β-(1,3)/β-(1,2) side-chain branched
CSBG	*Candida albicans*	Yeast	β-(1,3)/ β-(1,6) branched
Saccharomyces cerevisiae	*S. cerevisiae*	Yeast	β-(1,3) and small numbers of β-(1,6) branches
WPG-glucan (whole glucan particule)	*S. cerevisiae*	Yeast	β-(1,3)/β-(1,6) branched
Zymocel	*S. cerevisiae*	Yeast	Crude β-glucan extract
Zymosan	*S. cerevisiae*	Yeast	Crude extract with β-glucan and mannan non-uniform branches
GluP (fosforoglucan)	*S. cerevisiae*	Synthetic modified	β-(1,3) branched
PGG (betafektin)	*S. cerevisiae*	Genetically engineered	β-(1,3)/β-(1,6) highly branched
Glomerellan	*Glomerella cingulata*	Fungus	β-(1,3)/β-(1,6) branched
GRN (grifolan)	*Grifola frondosa*	Fungus/mushroom	β-(1,3)/β-(1,6) branched
LNT (lentinan)	*Lentinula edodes*	Fungus/mushroom	β-(1,3)/β-(1,6) branched
Pneumocytis carinii	*P. carinii*	Fungus/protozoan	β-(1,3)/β-(1,6) branched
P-SG (ganoderan)	*Ganoderma lucidum*	Fungus	β-(1,3)/β-(1,6) branched
SPG (sonifilan, schizophyllan)	*Schizophyllum commune*	Fungus	β-(1,3)/β-(1,6) branched
SR (skleoglucan)	*Sclerotium rolfssi* *S. glucanicum*	Fungus	β-(1,3)/β-(1,6) single branched
SSG	*S. sclerotium*	Fungus	β-(1,3)/β-(1,6) highly branched
LAM (laminarin, laminaran)	*Laminaria*	Algae i.e. brown seaweeds	β-(1,3) unbranched with some branching of β-(1,6)

β-glucans are commonly used, owing to their diverse physicochemical properties, to perform different functions in food technology, e.g. gel formation, foamability, stabilization, emulsification, water-binding and thickening. They are often used to improve the consistence of food products, e.g. drinks, dressings, fermented dairy products, dairy deserts or ice cream [13,14].

The molecular weights of β-glucans vary from tens to thousands of kilodaltons. The solubility of β-glucans in water is dependent mainly on their structure which is associated with their origin and increases with temperature. Protein-bound glucans are insoluble in water, only after partial hydrolysis, they produce gels. However, native β-glucan molecules lack this capability, so it can be said that β-glucans represent partly soluble and partly insoluble food ingredients [8].

β-glucan has been recognized to display many physiological functionalities and health benefits for humans; i.e. lowering blood glucose and insulin levels, reducing diabetic symptoms, improving lipid balance, reducing the risk of cardiovascular disease through its ability to lower serum cholesterol levels, and boosting the immune system and cancer prevention [15,16]. β-(1,3) (1-6)-*D*-glucans that have long, branched side chains are recognized as "good prebiotics", which stimulate the growth of beneficial intestinal flora [17].

β-glucans are also used as a supplement to animal feed as an immune enhancer to limit infection occurrence, improve animal growth and development and decrease the use of antibiotics [5,18,19]. In addition, β-glucans are used not only in medicine but also employed in cosmetic industry, mainly for preparations to prevent irritation and delay skin aging [17].

2.2 β-glucan from cereals

β-glucans, appear mostly in the cell walls of the aleurone, sub-aleurone and endosperm tissues of cereals, consisting of unbranched β-glucans with glucopyranose molecules linked by β-(1,3)- and β-(1,4) linkages, and has been widely used in food products due to the health-enhancing benefits. The content of β-glucans in cereal grains depends on the source (cereal species, cultivation conditions), processing treatments (milling, temperature-pH-shear effects, etc.) and interactions with other constituents (polymers or small molecular weight solutes) in the primary source or in a composite food matrix, of which designate the structural features and dispersibility-solubility of *β*-glucans, and thereby, modulate their physiological action in the gastro-intestinal tract [6,10]. The amount of *β*-glucans vary within the cereals, i.e. it is higher in barley (5-11%) than oats (3-7%) and wheat (0.2-1%) [2,6].

In barley *β*-glucan is mainly located in the endosperm and alerurone layer, which are consisted of 75% *β*-glucan + 20% of arabic gum and 26% *β*-glucan + 67% arabic gum, respectively. Wheat bran, consists of the outer coat (pericarp, testa and aleuron layers) of the wheat grain, is the main by-product of wheat milling, comprises approximately 6% *β*-(1,3)/*β*-(1,4)-glucan, used as the major resource for *β*-glucan extraction. However, the wheat aleurone layer contains 25% *β*-glucan. Thus, most of the recent research focuses on wheat kernel and wheat flour [20-21]. Biorklund et al. [22] stated that oat derived *β*-glucans, with high degree of water solubility, decreased significantly glycaemia and insulinemia than barley derived *β*-glucans that comprise lesser amount of water soluble components.

2.3 *β*-glucan from microorganisms

In general, in yeasts and other fungal cell walls *β*-glucans consist of glucopyranose molecules linked by *β*-(1,3) glycosidic linkages and small number of branches bound by 1,6-*β* bonds, whereas bacteria-derived *β*-glucans are not branched and include glucopyranose molecules linked by 1,3-*β* bonds [6].

A variety of bacteria, including important pathogens of humans, livestock and plants, produce extracellular and capsular polysaccharides (EPS), i.e. xanthan, dextran, pollulan and gellan, which are used on large scale in food industry for gelling, stabilizing and foaming properties [23]. These *β*-glucans are excreted from various microorganisms, such as *Pneumocystis carinii, Cryptococcus neoformans, Histoplasma capsulatum, Bacillus curdlanolyticus*, *B. kobensis*, *Sarcina ventriculi, Micromonospora, Agrobacterium* and *Rhizobacterium* [5,24-26].

Curdlan, isolated from *Agrobacterium* spp. and *Alcaligenes faecalis* var. *myxogenes*, exculisively containing *β*-(1,3)-glycosidic linkages, is a linear compound having a triple-helix conformation and a colourless and odourless compound which has been described as immunamodulator, anti-tumorogenic and anti-viral agent. It is insoluble in cold water, has unique rheological and thermal gelling properties and mainly used as a carrier for immobilized enzymes [27].

Fungi are an attractive source of physiologically functional foods and drug precursors, displaying a wide range of pharmacological activities such as anti-inflammatory, anti-tumor and immuno-modulating effects. The polysaccharide *β-D*-glucans are components that are found in some macrofungi (such as mushrooms), and unicellular fungi such as yeast (baker's yeast and *Candida albicans*) [28]. About half the mass of the fungal cell wall consists of *β*-glucans, but many are also excreted into the growth medium, making their recovery, purification and chemical characterization much simpler besides application in food and pharmaceutic industry [29]. Glucans differ in the structure of their side chains, water solubility, molecule size and molecular mass which are specific to the individual fungal species. The yeast and fungal glucans, either in water-soluble or insoluble forms, share the common structure: primary backbone chains of *β*-(1,3)-linked-glucopyranosyl units, along with randomly dispersed side chains of *β*-D-glucopyranosyl units attached by (1,6) linkages. These *β*-(1,3) (1,6)-glucans are usually highly branched; often present as an inner wall layer and are sometimes covalently associated with other cell wall polymers [30].

In yeasts cells the amount of *β*-glucans is higher than most cereal grains and vary between 29 and 64% depending on the cultivation conditions. Among yeasts, *Sacchromyces cerevisiae* is the major source of *β*-glucans comprising 55–60%. Other sources are *Zygosaccharomyces bailii*, *Kloeckera apiculata, Kluyveromyces marxianus, Debaryomyces hansenii,* and *Schizosaccharomyces pombe*. These *β*-glucans are built of glucose backbone with *β*-1,3 linkages, from which short side-chains branch off linked by *β*-(1,6) bonds [31].

Eventhough yeast-derived *β*-glucans are stated as being insoluble in water because of chitin, Akramiene et al. [26] pointed that *β*-glucans in inner layer of yeast cell wall are insoluble whereas the ones in outer layer are soluble. The insoluble *β*-glucans can induce immunity against bacterial, fungal, viral and parasite infections and against tumour cells [32], whereas the soluble form shows antioxidative properties [33]. Zymosan, derived from *Sacchromyces cerevisiae*, is an insoluble polymer of glucose, which demonstrates high antibacterial properties, induces inflammatory response and enhances immune system through activation of macrophages and induction of cytokine secretion [34].

Natural products containing fungal *β*-glucans have been consumed for probably thousands of years not only because of their nutritive but also because of improving general health and healing properties, especially in China and Japan [35,36]. The cell walls of macrofungi contain two polymers: chitin and *β*-glucan, in which individual chains are linked with hydrogen bridges and covalent bonds are formed between both polymers. Species of macrofungi used in ethnic medicine of the Far East are, *Ganoderma lucidum*, *Lentinula edodes*, *Grifola frondosa*, *Hericium erinaceus*, *Trametes versicolor*, *Schizophyllum commune*, *Phellinus linteus*, *Inonotus obliquus, Pleuortus ostreatus, Hirneola auricula*, *Stropharia aeruginosa*, *Agrocybe aegerita, Lyophyllum decastes, Calocybe indica, Armillaria melle* and *Collybia dryophila* [37,38].

The content of active substances depends on species, cultivation conditions, morphological stage (vegetative or reproductive) or part, maturation phase of fruiting bodies, storage conditions and processing methods [39,40]. In some members of the genus *Boletus* *β*-glucans comprise 2–13% of digestible dry matter [39], whereas in *Ganoderma lucidum* and Lingzhi mushroom *β*-glucan content is between 10 and 50% [41].

3. Physiological and health benefits of *β*-glucans

Many studies have indicated the beneficial health promoting effects of *β*-glucans, valuable functional ingredients, such as to lower the glucose and cholesterol levels in the serum, constipation relief, reduction of the risk of colorectal cancer, stimulation of the immune function, production of short chain fatty acids (SCFA) to promote the growth of beneficial gut microflora, prevention of coronary heart disease and diabetes, and increase the immunity to bacterial and parasitic infections [16,21,41]. The effect of decreasing blood glucose levels has been related to its property to form an unstirred water layer, which by resisting the convective effects of intestinal contractions, decreases sugar absorption by the small intestine [8,43]. Antitumour activity of *β*-glucans refers mainly to *β*-(1,3) (*1,6*)-form which has the ability to neutralise the free radicals, the vital reason of cancer occurrence [29].

It was reported that oat *β*-glucan could affect the upper part of the gastrointestinal tract of humans. After ingestion *β*-glucan starts to bind water, swell, form a gel-like network, dissolve in relationship to its size and previous hydrothermal treatments, and change the viscosity of gastrointestinal fluid. The increased volume causes a distension of the stomach, affects the satiety and reduces the rate of gastric emptying [12,44]. In the small intestine of humans, partly depolymerized during gastric ingestion, *β*-glucan remains intact, since no mammalian enzymes are capable of hydrolyzing it, and thereby act as a substrate for colon fermentations. As a prebiotic *β*-glucan affects the host by selectively stimulating the growth and/or activity of one strain or a limited number of bacterial strains in the colon, and thus, improves host health [45]. In the large intestine *β*-glucan behaves as a substrate, favoring production of SCFAs due to the oligosaccahrides favoring growth of some bacterial strains, enhancing production of microbial mass with good water retention properties, partly by its bulking effect [46].

Zhang et al. [47] reported that similar to other cereal-derived *β*-glucans, oat *β*-glucan, increased the insulin sensitivity index. As a soluble fiber of viscous characteristics it modifies the properties of chyme in the upper part of the gastrointestinal tract affecting gastric emptying, gut motility, and nutrient absorption, which are reflected in lower postprandial glycemic and insulin responses, which make *β*-glucan uptake beneficial for healthy subjects and patients with type-2 diabetes [48,49]. Since *β*-glucans decrease the blood cholesterol, improve the rheological property of blood, decrease the consumption of hepatic glucogen to increase the metabolism rate of glucose, and reduce the blood glucose level, due to the viscosity caused by the fiber and delay in intestinal absorbtion of carbohydrates it could have high significance in control and prevention of type-2 diabetes [50].

Due to the *β*-(1,3)-glycosidic bond, barley *β*-glucan has been reported to be capable of preventing cancer, reducing total serum cholesterol and low-density lipoprotein cholesterol (LDL) while increasing the high-density lipoprotein (HDL) cholesterol. Therefore, blends of food supplements containing barley *β*-glucan for specific health needs, mainly for prevention, treatment and control of diabetes, have been commercialized, such as pills, tablets and powders [9,51,52].

Some fungi-derived *β*-glucans, e.g. lentinan, schizophyllan, crestin, PSP and Grifron-D, are used in pharmaceutical preparations as antibacterial, antiviral and antiallergic agents [53,54] besides mentioned as having strong antioxidative properties [15]. As much as fungi-derived *β*-glucans may have stimulatory effects on the immune system, leading to resistance against viral, bacterial, parasitic, and fungal pathogens, the cereal-derived *β*-glucans have also been ascribed to have immune-stimulating properties. It was reported that natural *β*-glucans have antibiotic potential by increasing bacterial clearance, increasing bactericidal activity, increasing modulation of cytokine production, and increasing the number of monocytes and neutrophils [42,55].

In humans, fungal *β*-glucans, as for cereal *β*-glucans, have been shown to reduce both the overall level of cholesterol and the level of LDL cholesterol in blood. Lower levels of cholesterol is probably correlated with increased amounts of leptin, a protein-like substance, which is produced by fat cells of the subcutaneous connective tissues and is commonly found in blood. Since leptin control the feelings of hunger and satiety, it could be said that leptin mediates the feedback of fat content within the body and may offer a promising way to control obesity [56].

4. Industrial applications of *β*-glucans

Food industry may take the advantage of *β*-glucan, functional ingredient, having a growing market. Consumer demand for healthy and nutraceutical food is the major motive for this growth. However, to be used in products that offer a wide range of added health benefits its purity should be at high level In this context, *β*-glucans, extracted from different sources, have been marketed in various forms such as *β*-glucan concentrate extracted from oats (Oatrim™), *β*-glucan from barley (NutrimXe™) and *β*-glucan extracted from rice (Ricetrim™) [28,57].

Recent research is focused on exploration of the ways to incorporate *β*-glucans into various food systems, the emphasis mainly being on the rheological properties of *β*-glucan in water solution and viscoelasticity change under different food processing conditions. *β*-glucan has various applications in the food process industry as thickening, stabilizing, emulsification, and gelation agents to increase viscosity, substitute fat, and improve rheological properties in soups, sauces, beverages, and in other food products [13,58]. The functional properties of *β*-glucan, such as viscosity, foaming stability and emulsifying property, are affected mainly by the structure, molecular weight, conformation, temperature, and pH. The rheological properties of *β*-glucans are also correlated to their physiological properties. *β*-

glucan has high water holding capacity and gelling property. When dissolved in water, *β*-glucan form a viscous solution [2] of which the viscosity increases as the concentration of the solution or the molar mass of *β*-glucan increases [59].

Autio et al. [60] found that *β*-glucan exhibited good homogeneous property and viscous fluid characteristics when the concentration was below 1%; while the concentration increased to 2%, *β*-glucan performed heterogeneous property and viscoelasticity. All the changes happened in a very narrow range of concentration between 1–2%, which could be attributed to the strong interaction between the chains and aggregation at high concentration.

Effects of *β*-glucan on gelation and rheological characteristics of dairy-based products such as in yogurt [2,61-63], dairy gels [64] and cheese [65,66], low-fat ice creams [67], and low-fat cheese curds [68] have been investigated. Even dairy products are ascribed as not being a good source of fiber, they could serve as an alternative vehicle for the development of fiber-enriched foods. Sharafbafi et al. [69] incorporated high-molecular weight oat *β*-glucan into milk to obtain calorie-reduced and cholesterol-lowering dairy products, and the phase behavior, rheological properties, and microstructure of this dairy product were analyzed. The results showed that the flow behavior of the mixtures with concentrations higher than the binodal curve was not only governed by the presence of *β*-glucan chains, but also by the formation of these structures.

Its properties enable it to be incorporated alternatively in beverages as replacement for thickeners such as gum arabic, alginates, pectin, and carboxymethyl-cellulose [70]. Barley *β*-glucan is particularly well suited for such applications in beverages, as being capable of imparting a smooth mouth feel. The final product is described as an excellent source of soluble dietary fiber [7].

5. Conclusion

Currently numerous researches are being conducted on the impact of *β*-glucans on human health and its use in various foods and dairy products. The *β*-glucan from various resources have different molecular structures and thus display different physiochemical characteristics and rheological properties, which designate and limit their use in various food systems. However, due to the mentioned health benefits as a dietary fiber and textural impact on food systems, future research should aim utilization of *β*-glucans for the development of novel functional products.

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