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Beta-Glucan: An Overview of its Properties, Health Benefits, Genetic Background and Practical Applications

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Review Article

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Abstract: (1,3;1,4)-β-D-glucan is a soluble fiber, which is readily available in oat, barley and wheat grains that have been gaining interest due to its multiple bioactive and functional properties. *In vitro* and *In vivo* studies in animals and humans have proven and documented its beneficial role in reducing the risks of coronary heart disease, maintain insulin resistance, immune modulating properties and control dyslipidemia, hypertension and obesity. The fermentability of (1,3;1,4)-β-D-glucans and its ability to create very viscous solutions in the human gut brings these great health benefits. The viscosity of (1,3;1,4)-β-D-glucan depends on the physicochemical properties such as molecular weight, solubility, and concentration. The extraction conditions influence the rheology, viscosity, and molecular weight of (1,3;1,4)-β-D-glucan. Physicochemical properties of (1,3;1,4)-β-D-glucan are strongly affected by the genetic attributes and environmental condition. Members of the cellulose synthases (CesA) and cellulose synthase-like (Csl) genes superfamily responsible for the (1,3;1,4)-β-D-glucan synthesis. (1,3;1,4)-β-D-glucan as a food ingredient is broadly taken into consideration since its dual activity to increase the content of food products and to enrich their health properties. The wide range of effectiveness reported is explained by the properties of the β-glucan in the diets used, as well as the dose. This review provides comprehensive overview of the β-glucan including properties, applications, health benefits and recent advances of (1,3;1,4)-β-D-glucan research in several aspects.

Keywords: β-glucan, health benefits, rheological properties, extraction, fortification.

INTRODUCTION

(1,3;1,4)-β-D-glucan (hereafter referred as β-glucan) is a carbohydrate consisting of linked glucose molecules and a type of soluble fiber that is found in cereal grains, especially in barley and oats [1].

In addition, it is a major structural component of the cell walls of yeast, fungi and some bacteria. Various species of mushrooms such as Reishi, Shiitake, and Maitake [2] and certain kinds of seaweeds [3] are other sources of β-glucans. In barley and oat, β-glucan is mostly concentrated in the cell walls of the internal aleurone, sub-aleurone and endosperm tissues. Depending on the source, there are clear differences in macromolecular structure between β-glucans [4, 5].

From the point of the structure, the cell wall β-glucans of yeast and fungi consists of 1,3 β-linked glycopyranosyl residues with small numbers of 1,6 β-linked branches. In contrast, the oat and barley cell walls contain unbranched β-glucans with 1,3 and 1,4 β-linked glycopyranosyl residues, whereas β-glucans from the bacterial origin are unbranched 1,3 β-linked glycopyranosyl residues [6, 7]. The kind of linkage and branching differences in β-glucans cause the differences in molecular mass, solubility, tertiary structure, polymer charge and solution conformation. Therefore, the function of β-glucan is determined by its molecular structure [8].

β-glucans are beneficial to human health, where they represent soluble dietary fiber and reduce the risks of colorectal cancer, high serum cholesterol, obesity, non-insulin-dependent diabetes and cardiovascular diseases such as coronary heart disease and hypertension [9-11]. Also, β-glucan has immune modulating properties, increasing mineral and vitamin bio-availability, and play an important role in gut physiology and influencing spatial memory performance of children [12-15]. In 2006, the U.S. Food and Drug Administration (FDA) approved health-related claims stating that the intake of 3 grams of soluble β-glucan (from oat or barley) per day helps to effectively lower total blood cholesterol and LDL cholesterol, reduce the risk of cardiovascular disease (CVD), type II diabetes and colorectal cancer [16, 17].

With respect to the characteristics of the β-glucans, it is noteworthy that the isolation method may influence its characteristics. Therefore, differences can be expected between β-glucans differentially isolated from the same source. Extraction of β-glucan is a difficult task and special attention is required in order to obtain high-purity products with high yield. The extraction conditions could influence the rheology, viscosity, gel formation ability and molecular weight of β-glucan [18]. β-glucan has the ability to form highly viscous solutions [19]. However, the viscosity of β-glucan depends on the molecular weight, solubility, and concentration [20]. These properties make β-glucans to form highly viscous solutions in the human gut and considered as the basis of its health benefits.

The process for extraction of β-glucans is quite a strenuous process. The fraction rich in β-glucans are readily extracted from cereal grain in two ways. They are either taken by dry milling followed by sieving and air classification processes or by wet milling followed by sieving and solvent extractions [21]. Whatever the method, the extraction of pure β-glucan isolates is not straightforward. It has a relatively high cost due to the aleurone and subaleurone cell walls which enclose starch, protein and lipids [22]. Therefore, the pure β-glucan isolates are often ignored in food product development and relatively cheap oat and barley bran or flour fractions are typically used for development of food products.

Russia is the major producer of both barley and oats, producing 20.4 and 5.3 million metric tons respectively [23]. The major application of barley in Russia is in the malting and brewing industries. β-glucan is considered to play a negative role in the malting and brewing industries as it reduced the rate of wort filtration and haze formation in beer and adversely affect the recovery of malt extract. Therefore, a lot of research focused on the removal or degradation of β-glucan during malting process [24]. At the same time, β-glucans are considered to be anti-nutritive in feed formulations for monogastric animals and cause digestive problems [25, 26]

This review gives a comprehensive overview of β-glucan, in relation to fundamentals, health benefits, genetic background, and potential practical applications.

Properties of β-glucan

Glucans are glucose polymers, categorized according to their inter-chain linkage as being either *α*- or β-linked [27]. β-glucans are a heterogeneous group of non-starch polysaccharides, consisting of D-glucose monomers linked by β-glycosidic bonds [28]. The simplest glucan is the linear and unbranched β-(1,3)-D-glucan, found among prokaryotes and eukaryotes [29]. Another simple structural type occurs mostly in the non-lignified cell walls of cereal grains, and consist of linear β-(1,3;1,4)-D-glucans [30]. Branched structures of β-glucans consist of β-(1,3)- or β-(1,4)-glucan backbone with either (1,2)- or (1,6)-linked β-glucopyranosyl side branches [27]. Besides differences in the type of linkage and branching, β-glucans can vary in terms of frequency and length of branching, the degree of branching, molecular weight (from 102 to 106 daltons), polymer charge, solution conformation (random coil or triple or single helix) and solubility [31].

A large number of studies have indicated the beneficial physiological effects of β-glucan, such as the tendency to reduce blood glucose level and cholesterols, constipation relief, reduction of the risk of colorectal cancer, production of short chain fatty acids (SCFA) to promote the growth of beneficial gut microflora, and prevention of coronary heart disease and diabetes [8, 32, 33]. Also numerous animal experiments indicated that, apart from the prevention, it controls diabetes, reduction of cholesterol, flattening of the blood glucose levels, stimulate immune function and promotion of the growth of beneficial gut microflora [25, 26, 34]. Another study has demonstrated that dietary oat β-glucan can increase the endurance capacity of rats while facilitating their recovery from extreme tiredness [8].

Rheology is an important tool to study the physiochemical property of biopolymers, which could provide the characteristic property of polysaccharides indirectly, such as a conformational change in solution, gelling properties and the interaction between other compounds. The rheological properties of β-glucan is still under investigation, especially the effect of the molecular weight, pH value, temperature, shear rate and time, as well as the viscoelasticity of β-glucan at high concentrations [32].

The physiological functionalities of β-glucan are mainly depend on its water solubility and the characteristic properties in the small intestine. Even at the low concentration, the viscosity of β-glucan was relatively high; when the concentration is above 2 g/L, it exhibited pseudoplastic property where the viscosity decreased as the shear rate increases [35]. β-Glucan has high water holding capacity and gelling property. When dissolved in water, β-glucan could form a viscous solution. The rheological properties of β-glucan was closely correlated to its physiological properties [36].

Barley was mainly used in the brewing industry and animal feed but seldom utilized for human food. Due to the high viscosity of barley β-glucan, it may cause gelation induced clogging on the filter media of the beer-brewing process and digestion problems when fed to animals [37]. At equivalent β-glucan concentration, the viscosity of oat β-glucan was 100 times higher than that of barley β-glucan. Higher viscose oat β-glucan solution exhibited shear-thinning behavior, while barley β-glucan performed the Newtonian behavior, which was primarily attributed to differences in structural characteristics, such as molar mass [38].

Environmental effect

The level of β-glucan in cereal kernels was affected by genetic and environmental factors [39]. Usually, the genetic factor played a more important role than the environmental factor. Among all environmental factors, the amount of water supply during the barley maturing is the most crucial; the higher amount of water supply may result in the lower content of β-glucan in the barley kernel [40].

Molecular weight, solubility, and viscosity are important physicochemical properties of β-glucan, which are strongly affected by the genetic attributes of oat and barley grains [41]. For instance, oat β-glucans have a higher molecular weight than barley β-glucans [42]. Only 15-20% of barley β-glucans are water soluble while almost 70% of the oat β-glucans are soluble in water [43].

Health benefits

Reduce the chance of coronary heart disease

Coronary heart disease (CHD) incidence was strikingly lower in those who were originally eating more cereal fiber, which is comprised of β-glucan [44]. In addition, people who eat plenty of cereal fiber comprised of β-glucan are more health conscious in a variety of ways. Morris et al., [45] noted that they were less likely to smoke and Liu et al., [46] noted the reduction of alcohol intake, aspirin use and type of fat intake. Higher β-glucan intake also associated with higher intakes of dietary β-carotene, vitamins C and E. It is also associated with physical activities but there were no differences in age, body mass index (BMI). Many studies have been conducted to illustrate β-glucans as functional dietary fibers in reduction of CHD. A study conducted by Pietinen *et al*., [47] showed that, in age and treatment group adjusted analysis, water-soluble fiber were significantly inversely associated with risk of CHD events. Also, a significant inverse association between total dietary fiber intake and risk of CHD was found by Wolk *et al*., [48]. This was due to a significant inverse relation with cereal fiber comprised of β-glucan, but not with vegetable or fruit fiber. A 34% lower risk of CHD events were shown among the women in the highest quintile of cereal fiber intake in comparison to those who are in the lowest quintile [48].

Control obesity and metabolic syndrome

When considering the metabolic syndrome, central obesity is a well-defined component of the metabolic syndrome [49]. Many studies have been undertaken to use β-glucans as functional viscous dietary fibers in the management of various aspects of the metabolic syndrome. Dietary fiber has been documented for the effects on food intake, satiety and body weight [50]. The number of studies has proven, the reduction of body weight is related with diets enrich in dietary fiber or supplements of dietary fiber [51, 52]. A meta-analysis of 22 clinical trials have reasoned out that a 12 g increase in daily fiber intake is linked with a 10% reduction in energy intake while a 1.9 kg reduction in body weight during an average study conducted for a duration of 3.8 months [50]. Furthermore, soluble fibers with properties of viscosity producing, especially β-glucan, is more intensely related with reduction of hunger and appetite perceptions than low or no fiber condition [53]. Barley, a source of β-glucan, has satiating properties when fed completely. Experiments have described that after consuming barley before lunch to be significantly less hungry, but not wheat and rice containing foods [54]. In the same way, a preload of 5.2% barley β-glucan enriched biscuits significantly decrease appetite ratings in healthy teenagers, without modifying following food intake at lunch, as compared with control biscuits [55]. There are several factors, which decide the efficacy of β-glucan on satiety. Among them, dose leads on as the main determinant [56]. Also, this effect is mainly decided by solubility and molecular size of β-glucans [57]. Apart from that, the carrier food also plays a major role in determining the interaction of β-glucans with satiety. But, solid foods are well known to increase satiety and decrease hunger more efficiently than liquid foods [58].

Immunomodulation

Evidence accumulates that the composition of the diet influences the functioning of the human immune system. Therefore, changing dietary compositions as a tool to improve the immune function, currently receives a lot of attention [59]. Among polysaccharides that act as immunostimulants, β-glucans were found to be the most effective against infectious diseases and cancer [6]. *In vitro*, animal and human studies demonstrated that β-glucans can enhance the function and responsiveness of immune cells, stimulating both cellular and humoral immunity [60] and also activate the antimicrobial activity of mononuclear cells and neutrophils, and the functional activity of macrophages [28]. Furthermore, *In vivo* studies of a variety of β-glucans on the responses to pathogen infections in animals have recorded reduction of mortality and increased microbial clearance in lethally infected animals when exposed to β-glucans [61]. Some clinical studies have shown that pretreatment of high-risk surgical patients with intravenous yeast β -glucan enhanced survival, reduced intensive care unit stay length, and decreased the infection occurrence compare to a saline placebo injection [62, 63].

Control insulin resistance

Insulin resistance, whether or not go along with hyperglycemia, and type 2 diabetes are well-proven factors of metabolic syndrome [64]. In diabetic and nondiabetic individuals, it is a factor seen that several soluble fibers including β-glucan improve insulin sensitivity and reduce postprandial glucose and insulin responses [65]. In relation to other fibers, a smaller amount of β-glucan is required to reduce insulin responses and postprandial glucose in healthy participants [66], type 2 diabetic patients [67] and moderately hypercholesterolemic participants [68]. In type 2 diabetic participants, it was found that the intake of oat bran supplying 7.3 g β-glucan in a breakfast cereal lowered postprandial glucose responses more than an oat bran breakfast cereal supplying 3.7 g β-glucan [69]. Furthermore, it was found out that, in hypercholesterolemia individuals, the supplement of 5 g of oat β-glucan per day to a beverage used for 5 weeks reduced both insulin and glucose responses compared to the control beverage [70]. Out of the several mechanisms have been proposed to explain the glucose and insulin lowering property of β-glucan, the main component is the ability of β-glucan to form viscous solutions and delayed gastric emptying occurs increased digesta viscosity [71], slowing subsequent digestion and absorption [72]. High digesta viscosity decreases enzyme diffusion and stimulates the formation of the unstirred water layer, decreasing glucose transport to enterocytes [73].

Reduce dyslipidemia

Individuals with metabolic syndrome often present with athermogenic dyslipidemia, characterized by elevated concentrations of triacylglycerol's and low levels of HDL cholesterol in blood [49]. This lipid profile presents an individual with a high risk for cardiovascular disease. As far as the cholesterol metabolism is concerned, soluble fibers such as β-glucan play a significant beneficial role in reducing plasma total and LDL cholesterol levels and it has proved very effective [74]. Soluble fibers lowered LDL cholesterol concentrations by 5-10% in hypercholesterolemia and diabetic patients, when included in a low saturated fat and cholesterol diet [75]. In a study carried out on type 2 diabetic patients, it was found that the intake of a high-soluble fiber diet as 25 g/day over a period of 6 weeks reduces triglyceride concentrations by 10.2% [76]. The hypocholesterolemia functions of β-glucans are described by different mechanisms and out of them, one such mechanism is the altering bile acid excretion and the composition of bile acid pool. Dietary fibers increase bile acid excretion and activity of cholesterol 7α-hydrolase, which is a major enzyme responsible for cholesterol removal in the body [77].

Reduce hypertension

Hypertension is another main proved risk factor for heart diseases, stroke, and renal diseases [78]. It was found that the increased dietary fiber intake provided a safe and acceptable means to reduce blood pressure in patients with hypertension [79]. In a research on hyperlipidemic adults, reductions in blood pressure were observed following the consumption of a high fiber diet containing β-glucan as 8 g per day more than the unsupplemented food in the control diet, for over a period of 4 weeks [80]. Similarly, in a research on individuals with untreated elevated blood pressure or stage 1 hypertension, the intake of 8 g per day of supplemented soluble fiber from oat bran for 12 weeks period significantly lowered both systolic and diastolic blood pressure compare to the control [81]. The antihypertensive effects of β-glucan have been hypothesized under various mechanisms. Out of them, controlling insulin metabolism [82], improvements in endothelium-mediated vasodilation [83] and induced weight loss [84], are the potential mechanisms.

Gastrointestinal health

β-glucan may contribute to the healthy gastrointestinal condition because it cannot be digested by enzymes, such as salivary amylase. Moreover, it could inhibit the growth of metatrophic bacteria in the gastrointestinal tract, consistently provide vitamins, protect the liver, as it could improve the propagation condition of beneficial bacteria and enhance the microbial mass, such as lactic acid bacteria and *Bifidobacteria*. In the large intestine, β-glucan could be fermented by microorganisms, especially the lactic acid bacteria and *Bifidobacteria* in the cecum, and produce short chain fatty acids, which is beneficial to the human health [85]. Also, β-glucan performed as a prebiotic and beneficially affected the human health. A research on pigs indicated that consumption of barley β-glucan could stimulate the growth of more commensal gastrointestinal tract microbiota, as indicated by marker bacteria, such as *Lactobacilli* and *Bifidobacteria* [86].

Genetic background

In the grass family, barley, oat, and rye grains are rich in β-glucans, while wheat, rice, and maize have low concentrations [87]. Due to lack of information on genetic background of oat and rye β-glucan, here we discuss the genetic background of barley β-glucan only. The cell walls of the starchy endosperm of barley grain generally constitute considerably less than 10% of the grain, while the β-glucan component represents 2-10% of barley grain, depending on the variety and environmental conditions during grain development [87].

It has been suggested that type I polysaccharide synthases, are responsible for the synthesis of the backbones of wall polysaccharides such as cellulose, arabinoxylans, Xyloglucans and β-glucans

[88]. The type I polysaccharide synthases are encoded by a large multigene family known as the Cellulose synthase/Cellulose synthase-like (CesA/Csl) superfamily [89]. Sub-groups within this gene superfamily include the cellulose synthase sub-family (CesA) and cellulose synthase-like (Csl) sub-families CslA to CslJ, each of which consists of multiple genes [90].

The CslF gene family consists of ten associates [91] and is a part of the Cellulose Synthase gene superfamily, which is responsible for the production of several plant cell wall polysaccharides including β-glucan [89]. Variants among individuals of the CslF and CslH gene families' genes, that regulate them directly or indirectly, control the relative abundance and specific structure of β-glucans in both grain and rest of the plant [92]. The CslJ group of genes are also believed to be involved in β-glucan synthesis [93, 94].

The first functional identification of a gene capable of synthesizing β-glucan came from Burton et al. [95] who transformed the *Arabidopsis thaliana* with a cellulose synthase-like CslF2 gene from rice (*Oryza sativa*) and demonstrated the subsequent presence of a small amount of β-glucan in the dicot cell walls. In 2009, Doblin et al. [96] introduced a CslH gene from barley into *Arabidopsis* and this gene also promoted synthesis of detectable amounts of β-glucan. In 2014, Schreiber et al. [91] also investigated the ability of the CslF11 and CslF12 to synthesize β-glucan, by transient expression in *Nicotiana benthamiana*. Fincher [94] investigated the potential roles of CslH and CslJ genes in β-glucan synthesis in barley by using similar methods to those used for the functional analysis of the rice CslF genes in *Arabidopsis*.

Thus, it appears that three different CslF, CslH and CslJ gene families could be involved in the synthesis of β-glucan in barley and these gene families are members of the Cellulose synthases/Cellulose synthase-like (CesA/Csl) superfamily [90].

Extraction of β-glucan

Dry separation processing and wet separation processing are the two major techniques used in β-glucan extraction. The dry separation process, including pearling and air classification of meal or flour, are commonly employed due to being a simple and inexpensive procedure. The biggest advantage of dry processing is the avoidance of application of solvents. However, the recovery of β-glucan is usually less than 30 % [97]. The wet procedure is more complex but widely used in research, with 20-70 % of β-glucan generated in the final products [98].

Under the basis of above two categories, β-glucan can be typically measured by enzymatic-gravimetric methods. In addition to that, gravimetric, nonenzymatic gravimetric, and enzymatic chemical methods are also available [99]. Apart from the above-mentioned techniques, high-performance liquid chromatography (HPLC), gas-liquid chromatography (GLC), and ion-exchange chromatography are also used [100]. For example, β-glucans can be measured by McCleary and Codd method (Also known as AOAC method 995.16 and AAC method 32-23) [101]. It facilitates the analysis of a full range of dietary fiber constituents, which include resistant starches and nondigestible oligosaccharides, in a single test, without missing or double counting fiber compounds [102]. This method applies extended enzymatic digestion at 37 ^{0}C, followed by gravimetric isolation and quantitation of high molecular weight dietary fiber and liquid chromatography to quantitate low molecular weight dietary fibers [103].

Two AOAC methods have been adopted for the analysis of β-glucan in oats, barley, and their products. Both methods are enzymatic colorimetric methods that use lichenase to cleave 1,3 β-bonds in β-glucan to produce oligosaccharides of various lengths that are subsequently hydrolyzed to glucose with amyloglucosidase, and then the glucose is assayed colorimetrically [104]. The AOAC method 992.28 is applicable to measure β-glucans in oat and barley fractions, unsweetened oat cereals, and ready-to-eat cereals [105]. For the analysis of β-glucan content in flours from whole grains, milling fractions, and unsweetened cereal products, the AOAC method 995.16 is used [101]. In addition to AOAC methods, several methods including enzyme-linked immunosorbent assay (ELISA) [106], near-infrared spectroscopy(NIS) [107], and fluorescence assay [108], which specifically designed to measure β-glucan are also practiced.

Practical applications of β-glucan fortification

β-glucan fortification

There has been an expanding interest in β-glucan as a source of food ingredients and resources. Many industries are now in the process of finding mechanisms to extract pure β-glucan from cereal and their byproducts for food or cosmetics. Modern and updated methods are useful for the industrial utilization. Based on consumers' demands for health options, the food industry has aimed at developing new products towards functional foods and ingredients [99]. Since, β-glucan is readily available as a byproduct of oat and barley milling, it is generally used as a functional ingredient in foods. It also provides physiological benefits which are supported by health claims from many authorities [16, 17]. β-glucan is also found as a food ingredient as a powder using micro-particulation [109] or in the form of hydrocolloids [110].

Oats have been commonly used as an additive in the preparation of cereal products, by reducing water activity and consequently elongating durability [111]. Different types of oat-based breakfast cereals have received great success in the market. Adding 20% oat β-glucan into chocolate breakfast flakes protected the viability and stabilized the cells of *Lactobacillus rhamnosus*, a gut-friendly probiotic bacteria, at temperatures higher than 20 ˚C [112]. The incorporation of oats into baking products, has been widely tested [113]. When oat flour has been substituted for 10 % of fine wheat flour in bread, product quality improved in terms of crust color, bread softness, and taste [114]. Similarly, an oat component called Nutrim-5, a hydrocolloid preparation of β-glucans produced by treating oat grain or flour with a thermal process, improved the overall strength of pasta without negatively affecting either the quality or the sensory properties [115].

Oats are also used as additives in the production of yogurts with an increased amount of fiber [113]. Fiber addition increased the solidity ratio and texture of unsweetened yogurts, accelerated their acidification rate, and increased their viscosity [116]. When substituting fat with β-glucans hydrocolloid component at 3.47 % and 6.8 % in low-fat cheddar cheeses, a softer texture was described with decreased melting time and lowered sensory properties [117]. Due to its ability to mimic fat characteristics, oat fiber is one of the most effective ingredients in making low-fat meat products. It can be used to offset the poor quality associated with low-fat beef burgers [118] as well as low-fat sausages [119].

Effects of food processing on the biological activities of β-glucan

The physical, chemical and physiological properties of β-glucans altered by food processing. The physicochemical characteristics of β-glucan are affected by several processing techniques like cooking, freezing, and storing [120]. The solubility, which depends on extractability, naturally increases with processing due to depolymerization and β-glucan is released out from the cell wall. With the continuation of this degradation, gradually solubility decreases and insoluble β-glucan aggregates are created [121]. Researchers have revealed that, molecular weight reductions in similar products made from different grains [122, 123] and the reductions in molecular weight attributed to the effects of β-glucanase enzymes in wheat flour which is used to make these products [122]. The effectiveness of β-glucan in controlling glucose and insulin parameters, is related to the dose and viscosity, which can be altered during processing [30].

Challenges of β-glucan fortification

One of the major challenges faced by the functional food industry is developing functional foods with an acceptable taste to the average consumer [124]. Incorporating significant quantities of fiber into food products constitutes a technological challenge due to the possible deleterious effects on textural quality. The addition of fibers can be lead to alterations in the sensory characteristics, texture, and shelf life of foods due to their gel-forming ability, water binding capacity, fat mimetic, anticlumping, antisticking, texturizing and thickening effects [125]. Addition of β-glucan to milk and dairy products was reported to be an issue, due to its viscosity which may change the sensory characteristic of foods and due to its typical slimy texture in the mouth [19]. A study conducted for after 5 weeks shown that, beverages with 5 g of barley or oat β-glucan were rated higher than those with 10 g of barley or oat β-glucan [126]. These findings reveal that, β-glucan may impair the sensorial perceptions of foods, when chronically consumed. Hence, consumers are not willing to admit greater health benefits at the expense of deteriorations in the sensory characteristics of food products, and therefore the development of β-glucan fortified foods remains highly challenging [99].

CONCLUSION

This study provides a comprehensive overview of fundamentals, properties, health benefits, genetic background, practical applications and recent advances in research of β-glucan, useful for researchers and students for further studies and analysis. β-Glucan is a valuable functional ingredient that can provide numerous physiological functions and health benefits for humans, favoring its use in various food systems. The dose, form, molecular weight, and the carrier food of β-glucan shape its effects. The extraction conditions were highly influenced the quality, quantity, molecular weight and physiochemical properties of β-glucan. In future, extensive studies on investigation of physiological and rheological properties, biological effects and biosynthesis of β-glucan should be carried out. In addition, research should focus on development of new extraction method to obtain high quality and quantity β-glucans. Moreover, challenges of incorporating β-glucan into some food items without compromising their sensorial properties and their acceptance by consumers do still exist and need to be resolved.

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