Turkish Journal of Agriculture - Food Science and Technology, 10(10): 1957-1965, 2022
DOI: https://doi.org/10.24925/turjaf.v10i10.1957-1965.5430

Turkish Journal of Agriculture - Food Science and Technology

Available online, ISSN: 2148-127X | www.agrifoodscience.com | Turkish Science and Technology Publishing (TURSTEP)

Beta-Glucan as a Novel Functional Fiber: Functional Properties, Health Benefits and Food Applications

Zeynep Sinangil[1,a], Özge Taştan[2,b,*], Taner Baysal[3,c]

[1]*Food Engineering Section, Graduate School of Natural and Applied Sciences, Ege University, 35100 Bornova, İzmir, Türkiye*
[2]*Department of Food Engineering, Faculty of Engineering, Yeditepe University, 34755 Ataşehir, İstanbul, Türkiye*
[3]*Department of Food Engineering, Faculty of Engineering, Ege University, 35100 Bornova, İzmir, Türkiye*
[*]*Corresponding author*

A R T I C L E I N F O

Review Article

Received : 10/08/2022
Accepted : 27/09/2022

Keywords:
β-glucan
Functional food
Dietary fiber
Immune system
Prebiotic

A B S T R A C T

Recently the demand for functional food components such as prebiotics, probiotics, and phenolic compounds are increased. Nowadays, β-glucan, dietary fiber, and biologically active natural polysaccharide, exhibit properties like a prebiotic effect and immune system support. Furthermore, clinical studies have shown that daily intake of 250-500 mg β-glucan has several benefits on the immune system, showing low glycemic index, antimicrobial and anti-inflammatory properties. It is a polysaccharide composed of D-glucose monomers connected with β-glycoside bonds, found in natural sources like yeast (*Saccharomyces cerevisiae)*, some edible mushrooms, algae, and cereal grains. β-Glucan is more resistant and preserves its stability during food processing technologies (drying, freezing, etc.). Especially, β-glucan originated from baker's yeast (*S. cerevisiae)* has many immunostimulatory properties, such as hypoglycemic, anti-inflammatory, immune-modulatory, antioxidant, and anticancer activities. Also, the utilization of β-glucan in the food industry has increased regarding to their techno-functional properties like gelation, viscosity, solubility, and encapsulating agent. Therefore, this review highlights recently published research results on the functional properties, health benefits and clinical studies, the effects on the interaction with the other food compounds, and the potential food applications of β-glucans.

[a] *ozge.tastan@yeditepe.edu.tr* *http://orcid.org/0000-0001-7553-4005*
[b] *zeynep.sinangil@gmail.com* *http://orcid.org/0000-0002-2847-1424*
[c] *tanbay@hotmail.com* *http://orcid.org/0000-0003-1039-6275*

Introduction

Regarding the new developments in food science and technology, attention and awareness of consumers for the food and health relationship have increased. On the other hand, diseases such as diabetes, and chronic diseases, which are directly related to a healthy nutrition plan, have played an essential role in this demand for functional food products (Henry, 2010). Functional foods can be assorted as decreasing the risks of diseases and covering human health through their bioactive compounds. Medicinal plants have been used in food formulations and pharmacological designs since ancient times due to their functional properties such as antibacterial, antifungal, and antioxidant activities (Kına et al., 2021; Akgül et al., 2022; Mohammed et al., 2022). In addition, there is an increasing trend to use functional dietary fibers, prebiotics, probiotics, and phenolic antioxidants for novel food formulations. β-glucan is a prominent compound of this group, generally used to produce immune-boosting food products or supplements (Sevindik et al., 2017; Uysal et al., 2021).

The need for bioactive food ingredients that support the immune system has increased in the past two years. Especially after the COVID-19 pandemic, they have been widely used in food supplements to promote the immune system. β-glucan, a functional dietary fiber, has beneficial properties: it strengthens the immune system and promotes health with prebiotic characteristics. β-glucan is a polysaccharide composed of D-glucose monomers connected with β-glycoside bonds. Natural sources of β-glucan are yeasts, fungi, algae, barley, wheat, etc. (Rondanelli et al., 2009). Also, β-glucans are approved by EFSA (European Food Safety Authority) to use in food production (24 November 2011) (2011/762/EU). Then, FDA (Food and Drug Administration) also approved that they have several benefits by consumption and published guidance for the industry (June 2018) (21 CFR 10.30).

This review summarized and discussed functional properties of β-glucan, health benefits, and food applications.

What is β-Glucan?

β-glucan is a polysaccharide composed of D-glucose monomers connected with β-glycoside bonds. It is found in natural sources like yeast (*Saccharomyces cerevisiae*), fungi, algae, and cereal grains (barley, wheat, oat, etc.). β-glucans can also maintain their bioactivity after oral digestion, compared to the other dietary fibers (Geller et al., 2020). They have several proven health effects on the immune system and health. They lower the blood cholesterol, glycemic index and they improve the immune system of the body against pathogen microorganisms through their immunostimulatory and immunomodulating properties. They have proven anticarcinogenic effects by clinical trials where they can inhibit the growth of the tumor in the promotion stage and prevent tumor metastasis (Akramienė et al., 2007). According to the Turkish Food Codex, Nutrition and Health Regulations, it is suggested to enrich a serving of food product with 1.0 grams of β-glucan to decrease LDL cholesterol (17 July 2017) (Appendix 2).

Health Benefits of *β*-glucan on Human

β-glucans have several essential characteristics of human health. They strengthen the immune system, lowering glycemic index & LDL cholesterol levels, and gut microbiota modulation promotes health and blunts the glycemic-insulin response of the human body. Also, they play an active role in the growth of *Lactobacillus spp.* They improve the immune system of the body against pathogens by their immunostimulatory and immunomdulating properties. They have proven anticarcinogenic effects by clinical trials where they can inhibit the growth of the tumor in the promotion stage and prevent tumor metastasis (Akramienė et al., 2007).

Fractions of β-glucans exert different effects on human health. Soluble β-glucans are generally known for regulating cholesterol and glucose levels in the blood. Insoluble β-glucans are known by their immune-stimulating and modulating activities (Muthuramalingam et al., 2021). β-glucan with β-(1,3 and/or 1,6)-glycosidic linkages are only classified as biological response modifiers and have immunogenic properties (Geller et al., 2020; Muthuramalingam et al., 2021). EFSA approved the daily dose of β-glucan claims 3 g of β-glucans for lowering cholesterol.

Effects of β-glucan on Human Immune System

β-glucans are abundant polysaccharides found in nature; when they are bound to specific receptors in the immune system, they initiate phagocytosis. Phagocytosis is responsible for regulating inflammation and immune responses in the body, maintaining tissue homeostasis (Zhang et al., 2022). When β-glucan is ingested in the human body, they are most likely to show resistance to stomach acid and then they gradually pass through the first part of the small intestine. It is caught by macrophage receptors within the intestinal wall, passing through the Peyer's Patches in the gut-associated lymphoid tissue. Phagocytosis is started by the immune cells (Phagocytes) recognition of the *β*-glucan molecules as pathogen-associated molecular patterns through the receptors, which are known as pathogen recognition receptors. The PRRs like Toll-like immunoreceptors and Dectin-1 are present on the surface of phagocytes, including macrophages, cytokines, heterophils, and dendritic cells, they activate the immune system. Dectin-1 is the most commonly used receptor by β-glucans (Zhang et al., 2022). It is the most abundant receptor on dendritic cells, monocytes, and macrophages, providing efficient binding with the abundant β-glucans (Chodakowska et al., 2021). As a result of this activation, phagocytosis of foreign pathogens is enhanced, which results in a more efficient and long-term memory towards the pathogens (Novak and Vetvicka, 2008; Chan et al., 2009; van Steenwijk et al., 2021). The structure, solubility, and molecular weight of β-glucan directly effects its efficiency in phagocytosis. Insoluble β-1,3-glucan is known for its immune-modulating effects (Han et al., 2020; Geller et al., 2020; Muthuramalingam et al., 2021). Especially, β-glucans extracted from *Pleurotus* are found to be efficient on the immune system by their superior immunomodulatory properties, including stimulating phagocytosis directed against pathogenic microorganisms (Chodakowska et al., 2021). It directly initiates phagocytosis through Dectin-1 compared to the soluble form, which requires a dependent pathway activation. Molecular weight of β-glucans is also effective. For example, curdlan (1-3) with higher molecular weight can directly activate leukocytes to phagocytosis and produce inflammatory mediators and cytokines. On the other hand, low molecular weighted soluble yeast sourced β-glucan can cause antagonistic activities against macrophage production of reactive oxygens and cytokine synthesis by binding with Dectin-1 (Han et al., 2020; Zhang et al., 2022). Therefore, the specific physicochemical properties of the β-glucan can affect its role and efficiency in the immune system.

Structure and Chemical Properties of the β-Glucans

β-glucan is a polysaccharide composed of D-glucose monomers connected with β-glycoside bonds. In accordance with their source, structure, the degree of branching and type of glycosidic bonds connecting to the glycose monomers (($1 \rightarrow 3$), ($1 \rightarrow 4$), or ($1 \rightarrow 6$)), they are named as 1,3-glucans, 1,4-glucans, and 1,6-glucans (Chodakowska et al., 2021; Van Steenwijk et al., 2021). β-1,3 glucans (unbranched) are placed on the bacteria cell wall. β-1,3-1,4 glucans are found in cereal grains, while β-1,3-1,6 glucans are generally found in yeasts. They can be found in different shapes like a single, double and triple helix, worm-like, rod-like, and sphere-like. The most commonly used β-glucans are with β-(1,3 and/or 1,6)-glycosidic linkages found in triple helix structures in nature (Chodakowska et al., 2021).

Physicochemical Properties of β-Glucans

Solubility

β-glucans are very hydrophilic regarding their hydroxyl groups (OH^-) affluence in hydrogen bonding with water. This allows the molecule to hold water in both (soluble and insoluble) forms (Kaur et al., 2019). β-glucan's solubility relies on its structure and extraction method (Maneshwari et al., 2017).

Table 1. Fractions of β-glucans

Fraction of β-glucan	Sources of β-glucans
Soluble (dissolves and viscous gel-forming)	• High-molecular branched β-glucans (*Aureobasidium pullulans* (de Bary & Löwenthal) G. Arnaud 1-3/1-6) • Linear branched (Pleurotus ostreatus (Jacq.) P. Kumm 1-3) • Chemically modified β-glucans (Oligo-(1-3)-β -glucan-mannose)
Insoluble (water absorption)	• Yeast-sourced β-glucans (*Saccharomyces cerevisiae*, 1-3)

Table 2. Different and most utilized origins of β-glucan

Source	Structure	Content of β-glucan (%)	Mechanism of Benefit
Yeast (*S.cerevisae*)	Long β-1,6 to β-1,3	5-7	The immune system, wound treatment, inflammatory response
Algae (*Euglena graclis*)	1,3 linear	90	Immune system
Oat	1,3/1,4 linear	4-5	Cardiovascular diseases (lowering cholesterol and blood glucose)
Barley	1,3/1,4 linear	4.5	Cardiovascular diseases (lowering blood glucose)
Fungi (Mushroom)	1,3/1,6 short	15-40	Immune system
Brewer's Yeast	1,3/1,6 long	72	Immune system

Table 3. Different extraction methods and efficiencies

Source of β-glucan	Extraction method	β-glucan (%)	References
Yeast (*S.cerevisiae*)	Hot water extraction modified with deproteinization	82.7	Fu et al. (2022)
Oat bran	Enzymes and controlled temperature extraction	76	Immerstand et al. (2009)
Wheat bran powder	Ethanol treatment and enzymatic+alkaline	91.58	Wei et al. (2006)
Barley	pH 9.4 and 53–55°C	71.1	Burkus and Temelli (2005)
Barley	pH 7 and 8, 55 C	86.5	Temelli (1997)
Oat	Dry and wet milling processes with ethanol	15–20	Mälkki et al. (2013)
Barley	Acidic extraction with citric acid	80.4	Ahmed et al. (2009b)
Barley(waxy)	Hot water extraction (157.5 C, 45 min)	54	Benito-Román et al. (2013)
Barley	Enzymatic extraction	81.4	Ahmed et al. (2009a)
Barley bran	Alkaline extraction with NaOH	73-77	Bhatty (1995)

β-Glucans with β-(1→3) linkages with a higher degree of polymerization greater than hundred are insoluble in water. Furthermore, β-glucans with lesser polymerization degrees are highly soluble (Waszkiewicz-Robak, 2013; Mudgil, 2017). Soluble β-glucans differ from insoluble β-glucans by their different effects on health due to their functional properties (Mudgil, 2017). Also, they are separated by gel-forming (soluble) and non-gel forming (insoluble) given in Table 1. It is given that different sources of β-glucans can affect their solubility (Novak and Vetvicka, 2008; Han et al., 2020).

Viscosity and Molecular Weight

The viscosity of β-glucan depends on different attributes such as molecular weight and structure, solubility, and food matrix. β-glucan with a higher molecular weight and solubility have a higher capacity to reduce cholesterol compared to lower molecular weight and solubility (Mudgil, 2017).

β-Glucan with a higher molecular weight at lower concentration, forms viscous solutions while low molecular weighted β-Glucan forms a softer gel at high concentration. In research conducted on beverages enhanced with β-glucan, a comparison was made between high and low molecular weighted β-glucan. A beverage fortified with high molecular weight β-glucan improved the lipid and glucose metabolism compared to the lower one. Another study observed that β-glucan with low molecular weight was not effective to reduce glycemic response (Thondre and Henry, 2011). According to these molecular weights, viscosity has also played an active role in impacts of β-glucans, especially in managing human lipid and blood glucose levels (Thondre and Henry, 2011; Mudgil, 2017; Muthuramalingam et al., 2021).

Origins of β-Glucan

β-glucans are found in nature and can be extracted from several sources. Fungi, yeast, algae, barley, wheat, etc. They are found on the cell wall structure of several microorganisms (bacteria and fungi). Different sources of *β*-glucans are given in Table 2. They modulate the gut microbiota by maintaining their original form against the human digestive enzymes. Thus, they can play an active role in generating *Bifidobacterium* and *Lactobacillus* in the human digestive tract. (Lazaridou et al., 2004; Gupta et al., 2010; Murphy et al., 2021). In research, yeast glucan and mushroom glucan were found to boost the growth of *Bifidobacterium bifidum* and *Lactobacillus acidophilus* (Chodakowska et al., 2021). Each source of β-glucan has a different mechanism of benefit.

Table 4. Clinical trials

Origin of β-glucan	TYPE[1]	Purpose of application	Duration	Dose	Patients	Results	References
Oat β-glucan	1,3/1,4 linear	To examine the efficiency of nutraceuticals based on the combination of two different typed β-glucan (BG) (35% and 70%) at two different doses	6 weeks	2x day with a nutraceutical which contains 3 g per day or 5 g per day in two doses of 35% or 70% BG	4 groups of subjects were chosen (in each group, n=15)	5 g- 70% BG was efficient in type 1 obesity. Reduced LDL cholesterol, triglycerides, insulin, and total body fat percentage (TBF%) were observed.	Mateos et al. (2022)
Barley β-glucan	Soluble 1-3,1-4	To examine the effects of the bread containing barley β-glucan on metabolic syndrome.	4 weeks	The wheat bread was mixed with 3.4 g/100g of β-glucan. 6 g of β-glucan was consumed for 4 weeks.	43 subjects were chosen with diagnosed metabolic syndrome	The reduction was observed in the plasma cholesterol level. Significant changes were observed in microbiota composition. Also an increasement in bacterial groups: *Bifidobacterium* spp. and *Akkermansia muciniphila*	Velikonja et al. (2019)
Algae (*Euglena gracilis*)	1,3	To investigate the effects of the algae β-glucan on the immunity of the pigs.	17 days	Two different diet plans were followed as; 54 mg/kg and 108 mg/kg	*Escherichia coli* inoculated pigs were chosen as subjects.	The results have shown that 108 mg/kg of β-glucan 's intake by feed had immunomodulatory effects on weaned pigs. Inflammation was reduced, and diarrhea caused by *E.coli* was relieved.	Kim et al. (2019)
Wellmune	Insoluble 1-3,1-6	Lowering the occurrence of infections and flu in day-care settings	28 weeks	3×a day with the follow-up formula	250 subjects aged between 3-4 years	As a result of this study, fewer episodes and a reduced duration of acute respiratory infection were recorded, which resulted in less antibiotic utilization. Increasement in white blood cells was recorded, which promotes anti-inflammatory effects.	Li et al. (2014)
Wellmune (*Saccharomyces cerevisiae*)	Insoluble 1-3,1-6	To examine the effects of *S.cerevisiae*-based β-glucan on immunity and exercise induced upper respiratory tract infection patients.	28 days (post-marathon)	250 mg/day Wellmune	182 subjects who were physically active for 6 months were chosen. Aged between 29-46 years. 50 subjects were chosen in each β-glucan study and 30 in the placebo study.	This study has shown that β-glucan decreased the duration of URTI symptoms. β-glucan has also demonstrated improved mucosal immunity in subjects.	McFarlin et al. (2013)
Pleurotus ostreatus mushroom	Soluble 1-3,1-6	To investigate the anti-allergic effects and its efficiency on respiratory tract infections	12 months	The subjects took 1 mL of syrup (composed of 10 mg β-glucan and 10 mg vitamin C) every day	175 children aged between 2-5 and 6-10 were chosen in a placebo, double-blind study.	The results have shown that β-glucan was effective on allergic inflammation.	Milos et al. (2012)
Oat	1-3,1-4	Testing the effectiveness of 1.5 g and 3.0 g of β-glucan in lowering cholesterol	6 weeks	The experiment was applied in three steps (control group, 1.5 g and 3.0 g β-glucan groups)	87 mildly hypercholesterolemic women and men	As a result of this study daily consumption of β-glucan/d reduced LDL cholesterol in each group. A significant difference was not observed between 3.0 g and 1.5 g β-glucan groups.	Charlton et al. (2011)
S.cerevisiae	Soluble 1-3,1-6	To investigate β-glucan's immunomodulatory effects on breast cancer.	2 weeks	2×10 mg capsule (250 mg in each capsule)	23 female patients were diagnosed with breast cancer. 16 healthy female patients were chosen as a control group.	The results have shown β-glucan 's immunomodulatory effects on blood monocytes in short-term treatment.	Demir et al. (2007)

1: Type of branching (β-glucan)

Table 5. Food Studies

Origin of β-glucan	TYPE[1]	Purpose of application	Application	Dose	Food	Results	References
Oat and Yeast	1-3,1-4 1-3,1-6	To investigate the possibility of reducing shortening content and producing an improved high-quality food	Added into the structure of the biscuit	Yeast (91.31%) Oat (71.00%) in dry mass	Shortbread biscuits	The result has indicated that β-glucan could be an alternative to (%5) shortening in biscuits without any adverse effect on the product and sensory qualities.	Zbikowska et al. (2022)
Barley	1-3,1-4	Evaluation of sensory, glycemic response, and physiochemical properties of a biscuit enriched with β-glucan and isomaltulose as a sweetener	Added into the structure of biscuit	6% w/w 70% β-glucan	Cinnamon flavored biscuit	Glucose release was lowered. Differences in texture (hardness) were observed. The fortified biscuit was acceptable in organoleptic properties (flavor, sweetness, texture) by the diabetic individuals" group and control group, and they were thinner and softer.	Lazaridou et al. (2022)
Oat	1-3,1-4	To examine the effects of the noodle-making and cooking process on the structural qualities of β-glucan.	Oat B-glucan flour was added to the samples	4 different noodle samples were produced in different β-glucan amounts	Oat fortified noodles	The results have indicated that B-glucan 's health benefits can be more effective when mixed with complex food structures. It was recorded that β glucan reduced the starch digestion rate and glycemic index.	Nguyen et al. (2022)
Yeast	1-3,1-6	To investigate and compare yeast-sourced β glucan and carboxymethylglucan effects on turbot.	Soybean meal-based Turbot fish feeding	The diet contained 400 g/kg of soybean meal. The dose (yeast β glucan+ carboxymethylglucan) was given as 2 g/kg	Fish fed based soybean	The combination based on β-glucan and carboxymethylglucan enhanced the gut health of turbots. Also, they increased lysozyme, prebiotic activity	Gu et al. (2021)
Oat	1-3,1-4	To produce quinoa fortified with β-glucan-based milk.	Added into the quinoa-based milk	%30 w/w included in the mixture with other components as 0.1g/100 mL	Quinoa milk	Oat β-glucan efficiently improved the storage stability by increasing the viscosity, and it also prevented phase separation by producing a gel structure.	Huang et al. (2021)
S.cerevisiae	1-3	To prevent the spoilage of the pear by *Penicillium expansum*.	24h post-treatment and 2 h drying	β- glucan was used at different ratios; 0.01%, 0.10%, 0.20%, 0.50% and 1.00%	Pear	The results showed that β-glucan had increased the susceptibility to disease of Penicillium expansum	Sun et al. (2019)
Oat	1-3,1-4	To formulate and optimize a prebiotic sausage by using β-glucan and starch	Added into the structure of the sausage	13 trials were done by RSM In each application the sum od Resistant starch (RS)+ β-glucan(BG) +Starch(ST)=6%	Sausage	β-glucan addition on sausage samples have affected both physical and organoleptic qualities of the sausages.	Sarteshnizia et al. (2015)
Spent brewer's yeast	1-3,1-6	To examine the inclusion of β-glucan hydroxypropyl methylcellulose and whey protein's physical effects on bread	Added into the structure of the bread	1 g/100 g β-glucan was added into the formulation	Rise starch-based gluten-free bread	As a result β-glucan utilization in the bread has added several values to the bread matrix. The bread was found to be acceptable compared to wheat bread.	Kittisuban et al. (2014)
Oat	1-3,1-4	To produce reduced-calorie and cholesterol minimizer milk by the addition of high molecular weighted oat.	Added into the milk and examined	0.1 mg/mL water dissolved concentration.	Milk	The results have shown that β-glucan caused phase separation, which was noted as insignificant. Also, the addition of β-glucan caused shear thinning in the samples.	Sharafbafi et al. (2014)
Oat	1-3,1-4	To examine the effects of the inulin-based prebiotics on the growth of the prebiotics during storage	Added into the yogurt and examined	0.5 and 1% w/v	Yogurt	Prebiotic *L.plantarum* strains were increased in the last product	Kılıç et al. (2013)
Barley	1-3,1-4	the effects of barley fiber as a rich dietary fiber source in flatbread.	Added into the structure of Wheat flour-based bread	The addition of 20% of barley	Flat Bread	As a result the total β-glucan amount was increased from 0.2 g to 3.0 g.	Izydorczyk et al. (2008)

1: Type of branching (β-glucan)

Oat-extracted β-glucan is also known for reducing blood cholesterol and glucose concentration, affecting cardiovascular diseases (Zhang et al., 2022). Yeast-sourced β-glucan is insoluble, they are not digestible in the human body. They are widely used in the food industry as a thickening, emulsifying stabilizer, oil binding, and water holding agent (Fu et al., 2022).

β-glucan can also be obtained from different sources than traditional sources (cereals, yeast, fungi). A study conducted by Phuwadolpaisarn (2021) examined the β-glucan amount of different rice parts. The results showed that β-glucan amount in milled rice and rice bran was close to cereal-sourced β-glucans, they were found mainly in the endosperm and aleurone cell walls. Overall, β-glucans extracted from rice can be applied in supplements, food ingredients, and the cosmetic industry.

Fungi Origined β-Glucan

β-glucan extracted from fungi (1-3 bonded) was a natural food ingredient with high medical value and benefits on the immune system, stimulating the immune system. Lentinan, Schizophyllan, Krestin, Grifolan, and Pleuran are the most common non-toxic macrofungi. Lentinan (1,3-1,6) is known for its superior immunomodulatory and anticancerogenic properties; due to its low toxicity, and it is widely used by industry and researchers. Schizophyllan (1,3-1,6) also controls inflammation by stimulating the dectin-1 receptors. Krestin has proven benefits on cancer, especially prostate, lung, stomach, breast, liver, and colon. It also stimulates immune-boosting and prebiotic activities in the human body. Grifolan is known for its efficiency against diabetes and anti-tumor actions. Pleuran is widely used as a dietary supplement in the industry. It is also known as Immunoglukan and is effective against HSV (Herpes Simplex Virus) and infections (Chodakowska et al., 2021).

Extraction and Modification Methods

β-glucans are found naturally in the environment and sources. They require an extraction method to be used as a bioactive compound. Pretreatments were also found to improve the efficiency of the obtained β-glucans. Thus, in research conducted by Fu et al. (2022), different preparation techniques (deproteinization, deffating treatment, disruption, and drying methods such as freeze and vacuum drying) were applied to *S.cerevisiae* cells. They have found that deproteinization, freeze-drying, and defatted treatment have increased the binding capacity of the bile acids while improving the hypoglycemic attributes of β-glucan. (Fu et al., 2022). Therefore, the extraction methods of β-glucans depend and change through the sample. Different isolation methods are used in extracting β-glucans, such as hot water, alkaline, physical, mechanical, acidic, enzymatic, and other extractions (irradiation, ultrasound, microwave-assisted). In an experiment by Lopez-Perea et al. (2022), microwave effects were examined and discussed on barley kernels sourced β-glucans. Barley kernels were microwave heated for 4 and 8 seconds. A decrease in β-glucan elasticity was observed in 4 as compared to the control group and 8 s microwave application. On the other hand, *β*-glucan decreased after 4 s treatment. Overall, β-glucans can be more extractable, and the soluble fibers can increase by heating for a few seconds are suggested in microwave heating to increase their value and avoid significant changes in their properties. β-glucan is more resistant and maintains stability during heat applications and ultrasound (Geller et al., 2020).

These extraction methods directly affect the viscosity, molecular weight, solubility, etc. (Maneshwari et al., 2017; Kaur et al., 2019; Han et al., 2020). After the isolation, modification can be applied to enrich the bioactivity of β-glucans. These modifications (carboxymethylation, sulfidation, and oxidation) can improve its functional properties (Kaur et al., 2019; Han et al., 2020). The effect of different extraction techniques on the efficiencies of β-glucan obtained is given in Table 3.

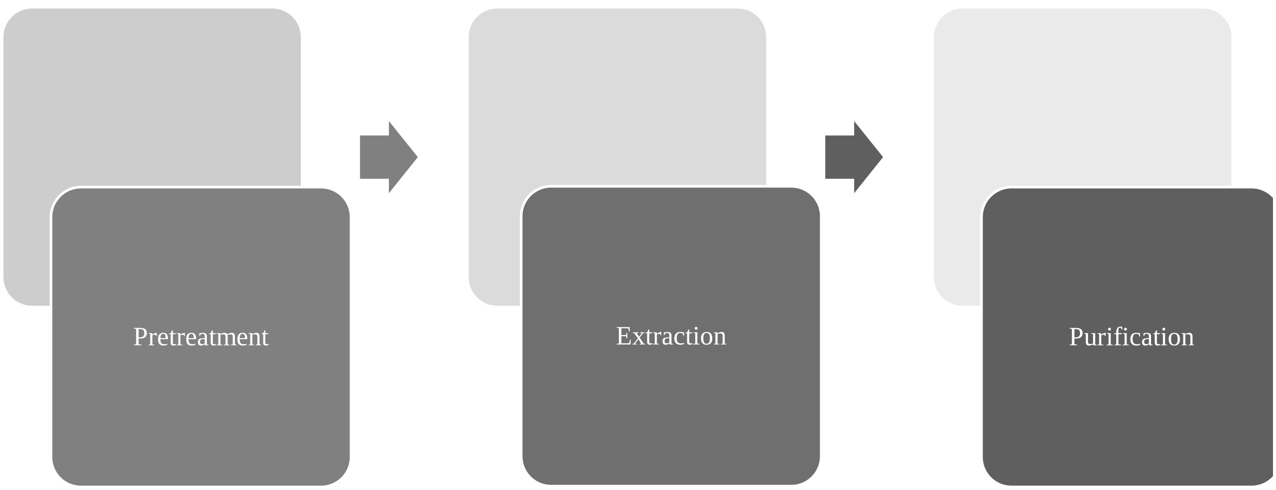

Figure 1. Extraction methods of β-glucan

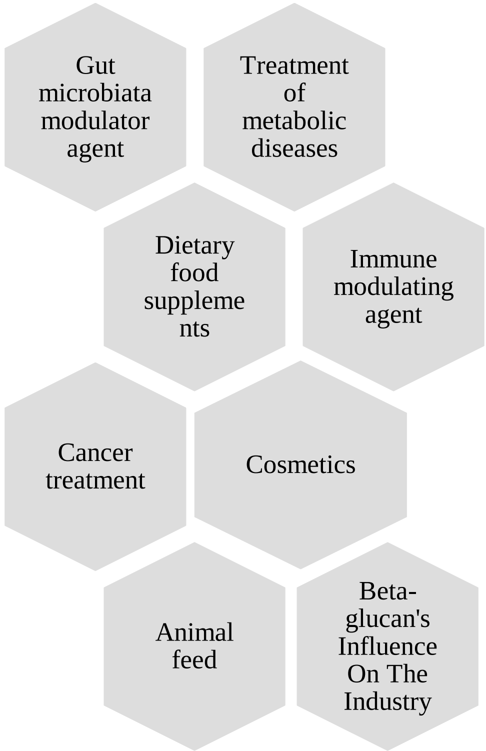

Figure 2. Application in the industry

Clinical Trials Conducted On β-Glucan

β-Glucans are known with several positive health effects by their proven anticarcinogenic, anti-tumor, and immune-modulating effects by clinical studies. Generally, fungi and yeast-sourced β-glucans were used for efficiency and proven benefits on human health (Geller et al., 2020; Muthuramalingam et al., 2021). Additionally, FDA (1997) reported that oat-sourced fiber is effective against LDL cholesterol and lowers total cholesterol around 5–10% at doses of 3 g/day. This amount is provided by around 55 g of oat bran (containing a minimum of 5.5% β-glucan) or 75 g of rolled oats (4% β-glucan). Thus, increased the research conducted on oat, barley, and other origined β-glucans. On the other hand, algae and barley were also applied for metabolical syndrome and against diarrhea. Clinical studies are shown in Table 4.

Food Applications of β-glucan

Several clinical trials have been conducted on β-glucan, and their superior benefits to human health have been proven. Besides their clinical benefits, they can show various effects in the food with their physicochemical properties. European Commission has approved two health claims (2012) for barley β-glucans. It was concluded that barley-sourced β-glucan is effective on reducing blood cholesterol (EU/ 2012a). Regarding this claim, it was allowed to include on the label of foods that provide a minimum of 1 g of barley β-glucan per calculated portion; more information should be provided to the consumers that its benefits are taken with a daily consumption of 3 g of barley β-glucan. In the second health claim, barley grain fiber's contributition into increased fecal bulk is given (EU/2012b). It is highlighted that this claim can only be used in food products which are high in fiber. 'High fiber' is listed in the Annex of Regulation (EC) No 1924/2006 (EC, 2006) as, i.e., ≥3 g β-glucan of barley grain fiber /100 kcal. These regulations and health claims have affected the demand for β -glucan enriched foods. Therefore, researchers and the food industry have increased their studies on food products enriched with β-glucan, applications in the food are given in Table 5.

Most recently, market research was conducted on β-glucan, and it was observed that its utilization in the food industry was increased. In China, functional food products have a large market and are widely used in food supplements and formulation. There is also current research on applying natural β-glucan as a functional nanomaterial in the food and pharmacy sector. Fungi-based bioactive coating material was used in the study conducted by Li and Peter (2019). They have found that it can be used as a coating material and has several benefits against immune-based diseases and cancer. β-glucans are generally utilized in fortifying food, as given in Table 5.

Conclusion

Regarding the increase in human awareness of food and health relationship, the demand for β-glucan in the market has also increased. Especially, β-glucan extracted from fungi has several functional properties like anti-inflammatory, antioxidant, and neuroprotective activities. Considering the immune-boosting effects of the insoluble β-glucan, the functional food products enriched with β-glucan against Covid-19 and other immune-related diseases have increased recently. Future studies should be proceeded to explore the chemical modifications and industrial applications of β-glucans in different industries such as food, medicine, cosmetics, and others. Furthermore, well-designed clinical studies are required to assess the mechanisms of action behind the effect of β-glucans on the immunostimulatory properties of humans.

Conflict of Interests

The author declares that for this article they have no actual conflict of interest.

Ethics Committee Approval

The author declares that this study does not include any experiments with human or animal subjects; therefore, no ethics committee approval is needed.

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