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Review Article

Beta-Glucan: An Overview of its Properties, sources, Health Benefits, immunity and Extraction methods.

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Abstract

A common homopolysaccharide made of D-glucose, beta glucan has a number of biological actions, such as anti-inflammatory, antioxidant, and anti-tumor effects. It is also found in cereals and microbes. More recently, there has been increasing evidence that β-glucan acts as a physiologically active compound that regulates adaptive immune responses, promotes dendritic cell maturation, and secretes cytokines. These processes are all directly linked to -glucan-regulated glucan receptors. This review focuses on the sources, characteristics, immunomodulatory properties, health benefits, extraction methods, and purification techniques of β-glucan.

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Introduction

With around 25,000 D-glucose units in either branched or unbranched form, β-glucan is a common non-starch polysaccharide made up of linear chains of β-D-glucose connected by **β-** (1 → 3), (1 → 4) and/or (1 → 6)-D-glycosidic linkage **[1].** Water-soluble glucans and water-insoluble glucans are the two categories into which glucans may be divided. the solubility of β-glucan may be impacted by molecular mass, composition, crude preparation, and chemical structure **[2].**

Furthermore, a significant structural element of the cell walls of some bacteria, fungus, and yeast is β-glucan. Other sources of β-glucans include several types of seaweeds and a variety of mushroom species, including *Reishi*, *Shiitake*, and *Maitake* mushrooms. The interior aleurone, sub-aleurone, and endosperm tissues' cell walls contain the majority of β-glucan in barley and oats. There are distinct variations in the macromolecular structure of β-glucans depending on the source **[3].**

As soluble dietary fiber, β-glucans are good for human health because they lower the risk of colon cancer, high blood cholesterol, obesity, non-insulin-dependent diabetes, and cardiovascular conditions like hypertension and coronary heart disease, Additionally, β-glucan modulates the immune system, increases the bioavailability of minerals and vitamins, has a significant function in gastrointestinal physiology, and influences children's spatial memory performance **[4].**

β-glucan extraction is a challenging process that demands extra care to produce high-purity products with a high yield. The extraction circumstances may have an impact on the molecular weight, rheology, viscosity, and gel formation capacity of β-glucan. It is possible for β-glucan to create very viscous solutions that acts as a physical barrier, limiting the access of digestive enzymes (e.g., amylase) to carbohydrates, further more increases the time food spends in the stomach by delaying gastric emptying. Nevertheless, the molecular weight, solubility, and concentration all affect β-glucan's viscosity. These characteristics are thought to be the foundation of β-glucans' health advantages since they cause them to produce very viscous solutions in the human stomach **[5].**

This review provides a thorough summary of β-glucan, including its basic properties, health advantages, genetic background, and extraction methods.

- **Sources of β-Glucans**

β-glucans come from a variety of sources, each of which offers distinct structures and possible health advantages **[6]**.

1. **Fungal Sources**: Fungi, especially mushrooms like ., *Reishi*, *Shiitake*, *Maitake* mushrooms and *Lentinula edodes*, are among the rich sources of β-glucans. The immune-boosting qualities of the beta-glucans found in these mushrooms have been thoroughly investigated. The biological activities of various species can be influenced by the major differences in their β-glucan structures. For instance, it has been demonstrated that the β-glucans extracted from maitake stimulate a variety of immune cells, strengthening the body's defenses **[7][8].**

2. **Yeast Sources**: Two more important sources of β-glucans are brewer's and baker's yeast (Saccharomyces cerevisiae). Because yeast-derived β-glucans have the ability to decrease cholesterol and modulate the immune system, they are frequently used in dietary supplements. The branching architecture of certain mushrooms contrast with the linear structure of yeast's β-glucans, which causes different immunological reactions **[9][10].**

3. **Cereal Sources**: Significant levels of soluble beta-glucans are found in several cereals, including barley and oats. These plant-based β-glucans have been investigated for their capacity to enhance intestinal health and decrease cholesterol. The main characteristic of oats' beta-glucans is their water solubility, which can help control blood sugar levels and encourage fullness, both of which are advantageous for managing weight. **[11][12]**

4. Additional sources: Certain bacteria and algae are among less well-known sources of β-glucans., for example, have demonstrated potential in bioactive applications and are found in the diatom Phaeodactylum tricornutum. Furthermore, β-glucans are produced by certain bacteria, like Lactobacillus and Bacillus, which add to the beneficial qualities of fermented foods. **[13]**

The derivatives of β-glucan

The structural alterations or modifications that can improve the functional qualities of β-glucan are known as derivatives.

Laminarin, a linear β-glucan mostly found in brown algae, is one prominent derivative. As a bioactive substance that may elicit immunological responses, laminarin is recognized for its immunomodulatory effects. It has been investigated for possible therapeutic advantages in a number of illnesses, such as infections and cancer. **[14]**

The mixed-linkage β-glucan (MLG), which is present in barley and oats, is another important derivative. Both the (1→3) and (1→4) links that make up MLG give it special viscosity and solubility characteristics. Because of its molecular structure, MLG functions as a soluble fiber that improves cholesterol levels and fosters the establishment of good gut flora, both of which support gut health. Because of the health advantages of consuming MLG, it is now included in dietary supplements and functional meals that focus on digestive and cardiovascular health. **[15]**

Furthermore, some bacteria, including *Alcaligenes Faecalis*, create the β-glucan derivative known as curdlan. Due to its remarkable gelling qualities, curdlan is used in the food sector as a stabilizer and thickening ingredient in a variety of goods. Curdlan and other β-glucan derivatives are also being studied for possible use in drug delivery systems, where their hydrogel-forming properties and biocompatibility can be used to release medicinal chemicals in a regulated manner. **[16]**

Overall, the β-glucan derivatives have a variety of biological activities and useful qualities that make them useful in the food, medicine, and nutraceutical sectors. Their potential to support health and well-being is highlighted by their immunomodulatory, prebiotic, and functional properties. The role of β-glucan derivatives in nutrition and medicine is expected to grow as more study is done on their various uses. **[17]**

Genetic background of β-glucan

Understanding the genes and enzyme pathways that are responsible for of the synthesis, modification, and regulation of β-glucan structures in various organisms—from fungus and plants to specific bacteria—is part of the genetic background of β-glucan. A more detailed investigation of its genetic components is provided below **[18][19].**

1. β-Glucan Synthase Genes

• **In fungi**, β-glucan synthesis is catalyzed by the β-1,3-glucan synthase enzyme complex, which is encoded by the FKS1, FKS2, and FKS3 genes. In pathogenic fungi such as *Aspergillus fumigatus* and *Candida albicans*, the FKS genes play a critical role in maintaining cell wall integrity and supporting survival under host conditions **[20].**

• **In Plants**: CSLA (Cellulose Synthase-Like A) and other genes involved in β-glucan synthesis in plants generate a variety of β-glucans, such as β-1,3/1,4-glucans in cereals, which function as structural and storage polysaccharides **[21].**

2. β-Glucan Modifying Enzymes

Enzymes frequently alter β-glucan after synthesis, influencing its molecular weight, branching, and solubility. The enzyme β-1,3-glucanase, which degrades β-1,3-glucan, is encoded by the fungal EXG1 gene. The fungal cell wall must be remodeled during growth, division, and host infection in order for this enzyme to function **[22].**

3.Regulatory Pathways

In fungi, the β-glucan synthesis is regulated in response to environmental stress by the PKC (Protein Kinase C) signaling route and the calcineurin pathway. Pathogens such as Aspergillus fumigatus can become more virulent due to reduced cell wall integrity caused by genetic changes that impact these mechanisms **[23].**

4. Variability of β-Glucan in Populations

The content and structure of β-glucans are influenced by genetic variety in plants and fungi, with certain strains or cultivars expressing larger quantities of β-glucans. Genetic variations in the genes encoding β-glucan synthase and modifying enzymes may be the cause of this diversity **[24].**

The characteristics of β-glucan

β-Glucans are polysaccharides that are mostly present in the cell walls of bacteria, yeast, algae, fungus, and some plants like barley and oats. They are specifically made up of glucose molecules connected by β-glycosidic linkages. These are a few of their main characteristics **[25]:**

1. Structural Composition

• Solubility: Cereals (such as barley and oats), fungi, and some yeasts are among the sources of β-glucan, a form of soluble dietary fiber. One important aspect influencing its physiological effects in the human body is its solubility. The ability of soluble β-glucans to dissolve in water and create a gel-like substance can alter the processes of absorption and digestion. This characteristic is important because it enables β-glucan to interact with the gut environment, which may improve glycemic management by encouraging a slower absorption of carbs **[26].**

• The source and molecular structure of β-glucan affect its solubility. For example, oat-derived β-glucans are generally more soluble than those from barley or yeast. The solubility of the β-glucan polymer can also be influenced by its molecular weight and degree of branching; larger branched structures are often more soluble. Because soluble β-glucans can bind to bile acids and enable their excretion, which eventually reduces cholesterol absorption, their solubility is essential for supporting positive health effects like reducing cholesterol levels and improving immunological function **[27].**

• Apart from its health advantages, β-glucan's solubility is essential for food processing and technology. Soluble β-glucans' capacity to gel can enhance the stability and texture of a variety of food products, increasing their consumer appeal. The creation of functional foods, which seek to offer health advantages beyond simple nourishment, is increasingly utilizing this characteristic. Thus, knowing β-glucan's solubility is crucial for nutritional research and the food industry, emphasizing its various functions in food technology and health **[28].**

• **Molecular Weight**: The source and extraction technique of β-glucans can have a substantial impact on their molecular weight. The molecular weight of β-glucans typically ranges from a few thousand to several hundred thousand daltons. For example, The molecular weight of oat-derived β-glucans is usually between 50,000 and 300,000 daltons, while that of barley-derived β-glucans can vary between 30,000 and 800,000 daltons. Since larger molecular weight β-glucans are frequently linked to stronger immunomodulatory effects, molecular weight plays a significant role in determining the biological activity of β-glucans. beneficial gut microbiota is promoted by lower molecular weight β-glucans because they are more soluble and readily interact with the intestinal mucosa. Higher molecular weight β-glucans, on the other hand, could assist the digestive system generate viscous gels that can help control cholesterol and glucose absorption. According to research, β-glucans' unique molecular weight is essential for their potential health advantages, which include anti-cancer, immune-boosting, and cholesterol-lowering activities. the distribution of β-glucans' molecular weight can also be affected by the extraction and purification procedures. Alkaline extraction, acid extraction, and enzymatic hydrolysis are some of the methods that can produce β-glucans with varying molecular weights that can be customized for use in medications, functional foods, and nutraceuticals. β-glucans are useful ingredients in dietary supplements and therapeutic treatments because their molecular weight is crucial for enhancing their functional qualities and health benefits **[29].**

• **Linkages**: β-glycosidic linkages attach glucose monomers to form β-glucans, which are polysaccharides. The kinds of β-glycosidic bonds between the glucose units can cause major variations in the structure of β-glucan. Fungi, oats, and barley are among the many sources of the most prevalent connections, which are β-(1,3) and β-(1,6) bonds. Fungal β-glucans are mostly made up of β-(1,3)-linkages in the backbone, with β-(1,6)-linkages creating side chains. Their immunomodulatory benefits, cholesterol-lowering qualities, and possible anticancer actions are all influenced by this structural variety. In order to improve the host's immune response and offer defense against different diseases, β-glucans interact with immune cells according to the precise arrangement of these connections **[30].**

β-glucans' solubility and molecular weight are important factors that affect their functioning in addition to their structural connections. When soluble β-glucans dissolve in water, they produce a gel-like material that can attach to bile acids, facilitating their excretion and helping to control cholesterol. On the other hand, insoluble β-glucans are a component of dietary fiber, which improves intestinal transit and encourages the development of advantageous gut bacteria. Because of this, β-glucans have gained interest in both their health advantages and their uses in nutraceuticals and functional foods. Utilizing β-glucans' therapeutic potential in the treatment of health and illness requires an understanding of their structural properties and connections **[31].**

2.Health Benefits

• **Lowering Cholesterol**: Studies indicate that β-glucan can lower blood cholesterol levels by preventing the intestinal absorption of cholesterol. Once in the digestive system, β-glucan binds to bile acids, which are produced in the liver from cholesterol, to create a gel-like material. This binding promotes the body to use more cholesterol to make new bile acids and stops the bile acids from being reabsorbed in the intestines. This can lead to a reduction in blood cholesterol levels, which can enhance heart health **[32].**

β-glucan's structure also affects how effective it is. The viscosity and solubility of β-glucan, particularly that obtained from oats and barley, enhance its ability to bind to bile acids. Low-density lipoprotein (LDL) cholesterol, also known as "bad" cholesterol, can be significantly reduced by eating at least 3 grams of β-glucan daily, according to studies **[28][29].** The disease known as atherosclerosis, in which arteries constrict and stiffen as a result of cholesterol plaque accumulation, is less likely to occur when β-glucan is used to decrease LDL levels. On top of that, β-glucan has no effect on "good" or high-density lipoprotein

(HDL), which is crucial for removing excess cholesterol from arteries **[33].**

• Global health authorities have acknowledged β-glucan's ability to decrease cholesterol. β-glucan is becoming more and more well-liked as a dietary supplement and functional food component for those at risk of cardiovascular disease because of its natural source and possible health advantages **[34].**

• **Blood Sugar Control:** Polysaccharides called β-glucans, which are present in the cell walls of bacteria, fungus, and certain plants, are well-known for their many health advantages, including their ability to regulate blood sugar levels. These substances have the unusual capacity to slow down the absorption of carbs by creating a viscous solution in the stomach. β-glucans assist postpone the breakdown and absorption of glucose by forming a gel-like material during digestion, which results in more stable blood glucose levels after meals. For those who have diabetes or insulin resistance, this impact is especially beneficial since it helps avoid blood sugar spikes that over time may exacerbate these diseases **[35].**

The β-glucans can improve insulin sensitivity, which will help the body better control blood sugar. Furthermore, β-glucans have an impact on the gut microbiota, which in turn has an indirect effect on blood sugar management. These substances support better metabolic health by encouraging good gut flora, which can have a favorable effect on glucose regulation. In order to assist maintain appropriate blood sugar levels, foods high in β-glucans, such barley, oats, and some types of mushrooms, are advised as part of a balanced diet **[36].**

• **Digestive Health**: the β-glucans is important for maintaining digestive health therefore after being consumed, β-glucans acts as a prebiotic, which means it provides sustenance for good gut bacteria and helps maintain the balance of the gut flora. For the best immunological support, nutritional absorption, and digestion, this balance is essential. By encouraging mucus secretion and strengthening the intestinal lining, β-glucans also improves the function of the gut barrier, preventing the transfer of toxic substances and pathogens from the gut into the circulation. β-glucans is also known to be a useful nutrient for supporting gut health and improving overall digestive function because it helps maintain stable blood glucose levels by regulating the release of sugars, which can also have a positive effect on digestion and metabolic health **[37].**

Immunostimulatory Properties of β-glucan

The β-glucans are highly valued for their ability to stimulate the immune system. They are advantageous in both preventive and therapeutic settings since they are essential in stimulating different immune system components. An explanation of their immunostimulatory actions is provided below:

1. Innate Immunity Activation: Certain receptors on immune cells, such as dectin-1 on neutrophils and macrophages, may identify β-glucans. The generation of cytokines (such as TNF-α and IL-6) that boost immune activity is the result of binding to these receptors, which sets off a series of immunological reactions **[38].**

2. **Increase of Phagocytosis**: β-glucans enhance phagocytosis, the process by which immune cells take up and eliminate infections, by activating neutrophils and macrophages. This improvement aids in the more effective removal of infections and may increase defenses against fungus infections and some types of cancer **[39].**

3.**Adaptive Immunity Stimulation**: β-glucans affect the adaptive immune response in addition to mainly activating the innate immune system. They activate dendritic cells, which in turn better display antigens, resulting in a stronger T and B cell activation. Long-term immunity and antibody generation depend on this factor **[40].**

4-β-glucans have **anti-inflammatory properties** that assist control inflammation in addition to boosting immune responses. They prevent tissue damage by reducing excessive inflammation by maintaining a balance between pro- and anti-inflammatory cytokines **[42].**

5. **Anticancer Properties**: β-glucans have been thoroughly investigated for their anticancer properties, and there is strong evidence that they play a part in immune regulation and cancer treatment. They have the ability to stimulate different immune cells, such as neutrophils, macrophages, and natural killer (NK) cells, to identify and destroy tumor cells **[43].** By binding to certain receptors on these immune cells, such Dectin-1 and CR3, β-glucans are able to target and eliminate cancer cells by phagocytosis and cytotoxicity when they are delivered into the body. Further boosting immune responses against malignancies, β-glucans also trigger the production of cytokines. Clinical research has demonstrated that by decreasing tumor growth and halting metastasis, β-glucans can enhance the effectiveness of traditional cancer treatments like chemotherapy and radiation. These characteristics make β-glucans a viable adjuvant in the treatment of cancer, with the potential to improve patient outcomes and quality of life **[44].**

Anti-inflammatory Properties of β-glucan

The anti-inflammatory activities of β-glucans are well-established and mostly ascribed to their capacity to regulate immunological responses. Yeast, fungus, barely, wheat and oats have these polysaccharides in their cell walls. They interact with immune cells, especially neutrophils and macrophages, to trigger a variety of reactions that lessen inflammation.

Mechanisms of Anti-inflammatory Action of β-glucans:

1. Modulation of Cytokine Production: β-glucans have an impact on the release of cytokines, which helps to promote anti-inflammatory cytokines (like IL-10) and decrease pro-inflammatory cytokines (like TNF-α, IL-1β, and IL-6). When it comes to chronic inflammatory disorders, this aids in preserving a balance that reduces inflammation **[45].**

2. **Activation of Macrophages and Neutrophils**: β-glucans connect to certain receptors on immune cells, such as Dectin-1 and CR3, which causes the macrophages and neutrophils to remove debris and pathogens without triggering an excessive inflammatory response, reducing tissue damage.

3-Inhibition of NF-κB system: One important signaling system implicated in inflammation, the NF-κB pathway, can be inhibited by β-glucans. β-glucans stop the transcription of genes linked to inflammatory reactions by inhibiting this pathway **[46].**

4. **Reduction of Oxidative Stress**: Reactive oxygen species (ROS) are frequently produced by inflammatory processes, which can result in oxidative stress, which in turn can reduce inflammation. Since β-glucans have antioxidant qualities, they can help lower ROS levels, which in turn helps lessen inflammation **[47].**

Extraction of β-glucans

The source material and required purity will determine which of the several procedures used to extract β-glucans is used. Typical extraction methods consist of:

1. Alkaline Extraction: Because it effectively dissolves β-glucans from cell wall structures, alkaline extraction is one of the most used techniques. Usually, an alkaline solution (such as sodium hydroxide) is applied to the biomass at high temperatures during the process. β-glucans dissolve into the solution as a result of this treatment's disruption of the cell wall matrix. A number of variables, including the alkali content, treatment time, and temperature, might affect the extraction efficiency. Following extraction, ethanol or isopropanol can be used to precipitate the β-glucans, which can then be cleaned and dried to provide a pure product **[48][49].**

2. Acid Extraction: This technique breaks down cell wall components to liberate β-glucans by using acidic solutions, such as sulfuric or hydrochloric acid. Although β-glucans can be produced with this approach, certain polysaccharides may be broken down or undesirable side effects may result from the acidic environment. To separate the β-glucans after extraction, neutralization and precipitation are required **[50].**

3. Enzymatic Extraction: This method releases β-glucans into the solution by selectively breaking down cell wall polysaccharides using certain enzymes such as cellulases and hemicellulases. Compared to chemical techniques, enzymatic extraction has the benefit of being more selective and potentially producing better purity. The acquisition of enzymes and the requirement for ideal reaction conditions, however, might make the procedure expensive. The effectiveness of this extraction technique depends critically on variables including temperature, reaction duration, and enzyme concentration **[51].**

4. Hot Water Extraction: Boiling the raw material in water is one of the most basic extraction methods. Heat aids in the dissolution of soluble β-glucans, which can then be concentrated using precipitation techniques or water evaporation. Although hot water extraction is simple and inexpensive, it frequently produces inferior purity since other soluble polysaccharides and chemical compounds are also extracted **[52].**

Purification and Characterization Processes

Purification is necessary after extraction in order to remove of contaminants and other non-target substances. Higher purity levels can be attained by using methods including dialysis, centrifugation, and filtration techniques. Furthermore, chromatographic techniques including size-exclusion chromatography and high-performance liquid chromatography (HPLC) are commonly employed to further purify and analyze the β-glucans Following purification, characterization is performed to ensure the β-glucans meet the desired structural and functional standards. Techniques such as mass spectrometry, Fourier-transform infrared (FTIR) spectroscopy, and nuclear magnetic resonance (NMR) spectroscopy can reveal information on the molecular weight, molecular structure, and functional groups found in β-glucans. Since many structural features might affect biological activity and efficacy, this knowledge is essential for both research and application **[53][54].**

Side Effects of Glucans

Beta-glucans are generally considered safe, particularly when consumed through natural food sources. However, when used in concentrated forms or supplements, the following side effects may occur:**[55]**

1. Gastrointestinal Issues

- **Common Symptoms**: Bloating, gas, diarrhea, or stomach discomfort, especially in individuals not accustomed to high-fiber diets.

2. **Allergic Reactions**

- **Rare Cases**: Individuals allergic to the source of beta-glucans (e.g., yeast, oats, or barley) may experience symptoms such as rash, itching, or respiratory discomfort.

3. **Interference with Mineral Absorption**

- High intake of beta-glucans might reduce the absorption of certain minerals, such as calcium, magnesium, and zinc, due to their gel-forming properties in the gut.

Benefits of Beta-Glucans for Skin

Their skin benefits are largely attributed to their ability to interact with the immune system, improve skin hydration, and promote healing.

Here are several key ways beta-glucans support skin health**:[56]**

1. Beta-glucans have excellent water-binding properties, which help to retain moisture in the skin.
2. Beta-glucans are involved in tissue regeneration and repair.
3. beta-glucans can help minimize scarring and improve the appearance of the skin post-injury.
4. Beta-glucans stimulate fibroblasts in the skin, which are responsible for collagen production.

Conclusion

In this review, the principles, characteristics, health advantages, genetic background, and extraction techniques are all thoroughly covered. beneficial for students and researchers to do more study and analysis in the field of β-glucan investigations. The usage of β-glucan in different food systems is preferred since it is a useful functional element that may offer multiple physiological functions and health advantages to people.

Further research on the production of β-glucan, biological impacts, and physiological and rheological characteristics should be conducted. In order to get high-quality and quantity β-glucans, research should also concentrate on developing innovative extraction techniques. Furthermore, it is still difficult to add β-glucan to some foods without losing their sensory qualities or consumer approval, and this problem has to be fixed.

β-glucans regulation of the immune response in humans has promise for enhancing immune function and opening up new therapeutic options for anti-inflammatory, anti-tumor, and anti-infection conditions. It is anticipated that the functionally further assessed beta glucans will be used more and more often as research into their immunological role and associated mechanism of action continues.

References

1-Kaur, R., Sharma, M., Ji, D., Xu, M., & Agyei, D. (2019). Structural features, modification, and functionalities of Beta-Glucan. Fibers, 8(1), 1e29.

2-Xiu, A., Zhan, Y., Zhou, M., Zhu, B., Wang, S., Jia, A., Dong, W., Cai, C., & Zhang, J. (2011). Results of a 90-day safety assessment study in mice fed aglucan produced by Agrobacterium sp. ZX09. Food and Chemical Toxicology, 49(9), 2377e2384.

3- Wood PJ. Oat β-Glucan: Properties and Function. In: OATS: Chemistry and Technology. Second Edition. AACC International Inc, USA, 2011;219-54.

4. Ina K., Kataoka T., Ando T. The use of lentinan for treating gastric cancer. Anticancer Agents Med. Chem. 2013;13:681–688. doi: 10.2174/1871520611313050002.

5- Khawaja Muhammad Imran Bashir , Jae-Suk Choi. Clinical and Physiological Perspectives of β-Glucans: The Past, Present, and Future. Int J Mol Sci. 2017 Sep 5;18(9):1906.

6.panelJunying Bai , Yikai Ren , Yan Li , Mingc ong Fan , Haifeng Qian , Li Wang , Gangche ng Wu , Hui Zhang , Xiguang Qi, Meijuan X u , Zhiming Rao. Physiological functionalities and mechanisms of *β*-glucans Trends in Food Science & Technology, Volume 88, June 2019, Pages 57-66

7.Nakashima A., Yamada K., Iwata O., Sugimoto R., Atsuji K., Ogawa T., Ishibashi-Ohgo N., uzuki K. β-Glucan in Foods and Its Physiological Functions. J. Nutr. Sci. Vitaminol. 2018;64:8–17. doi: 10.3177/jnsv.64.8.

8. Xiao Z., Zhou W., Zhang Y. Fungal polysaccharides. Adv. Pharmacol. 2020;87:277–299. doi: 10.1016/bs.apha.2019.08.003

9. Volman, Julia J (20 November 2007). "Dietary modulation of immune function by β-glucans". *Physiology & Behavior*. **94** (2): 276–284.
10. Nakashima A, Yamada K, Suzuki K (2018). "β-Glucan in Foods and Its Physiological Functions". *Journal of Nutritional Science and Vitaminology*. **64** (1): 8–17
11. Chu, YiFang (2014). *Oats Nutrition and Technology*. Barrington, Illinois: Wiley Blackwell
12. Yunzhen Zhang, Yueqin Li, Qiang Xia, Lianliang Liu, Zufang Wu & Daodong Pan (2021): Recent advances of cereal β-glucan on immunity with gut microbiota regulation functions and its intelligent gelling application, Critical Reviews in Food Science and Nutrition.
13. Muthukumaran Jayachandran, Jiali Chen, Stephen Sum Man Chung , Baojun XuA critical review on the impacts of *β*-glucans on gut microbiota and human health. The Journal of Nutritional Biochemistry, Volume 61, November 2018, Pages 101-110.
14. Kaur R., Sharma M., Ji D., Xu M., Agyei D. Structural Features, Modification, and Functionalities of Beta-Glucan. Fibers. 2020;8:1. doi: 10.3390/fib8010001.
15. Li Zha , Shennan Wang , Lars A. Berglund , Qi Zhou. Mixed-linkage (1,3;1,4)-β-d-glucans as rehydration media for improved redispersion of dried cellulose nanofibril. Carbohydrate Polymers, Volume 300, 15 January 2023, 120276.
16. Jun Liu , Jiqing Tang , Xiuting Li , Qiaojuan Yan , Junwen Ma , Zhengqiang Jiang . Curdlan (*Alcaligenes faecalis*) (1→3)-β-d-Glucan Oligosaccharides Drive M1 Phenotype Polarization in Murine Bone Marrow-Derived Macrophages via Activation of MAPKs and NF-κB Pathways. Molecules. 2019 Nov 22;24(23):4251.
17. Fengmei Zhu, Bin Du , Baojun Xu. A critical review on production and industrial applications of beta-glucans. Food Hydrocolloids. Volume 52, January 2016, Pages 275-288
18. Schwerdt JG, MacKenzie K, Wright F, Oehme D, Wagner JM, Harvey AJ, et al. Evolutionary dynamics of the cellulose synthase gene superfamily in grasses. Plant physiology.2015;168(3):968-83.
19. Schreiber M, Wright F, MacKenzie K, Hedley PE, et al. The barley genome sequence assembly reveals three additional members of the CslF (1,3;1,4)-β-glucan synthase gene family. PloS one. 2014;9(3):e90888.
20. Sumanun Suwunnakorn , Hironao Wakabayashi , Milena Kordalewska , David S Perlin , Elena Rustchenko. *FKS2* and *FKS3* Genes of Opportunistic Human Pathogen *Candida albicans* Influence Echinocandin Susceptibility. Antimicrob Agents Chemother . 2018 Mar 27;62(4):e02299-17
21. Yang Zhou, Yi-Hong Gao, Bao-Cai Zhang, Han-Lei Yang, Yan-Bao Tian, Yi-Hua Huang, Cui-Cui Yin, Jian-Jun Tao, Wei Wei, Wan-Ke Zhang. CELLULOSE SYNTHASE-LIKE C proteins modulate cell wall establishment during ethylene-mediated root growth inhibition in rice . *The Plant Cell*, Volume 36, Issue 9, September 2024, Pages 3751–3769,
22. Valentina Scafati , Francesca Troilo, Sara Ponzian, Moira Giovannoni, Anna Scortica , Daniela Pontiggia, Francesco Angelucci, Adele Di Matteo, Benedetta Mattei and Manuel Benedetti.Characterization of two 1,3-β-glucan-modifying enzymes From Penicillium sumatraense reveals new insights into 1,3-β-glucan metabolism of fungal Saprotrophs. Biotechnology for Biofuels and Bioproducts (2022) 15:138
23. Dahui Wang , Zhibo Zhao , Youhua Long , Rong Fan .Protein Kinase C Is Involved in Vegetative Development, Stress Response and Pathogenicity in *Verticillium dahlia. Int* J Mol Sci. 2023 Sep 19;24(18):14266.

24. Xuemei Zhong , Guoqing Wang , Fu Li, Sixian Fang , Siai Zhou , Akihiro Ishiwata , Alexander G Tonevitsky , Maxim Shkurnikov , Hui Cai , Feiqing Ding . Immunomodulatory Effect and Biological Significance of β-Glucans. Pharmaceutic. 2023 May 29;15(6):1615.
25. Barsanti L, Passarelli V, Evangelista V, Frassanito AM, Gualtieri P. Chemistry, physico-chemistry and applications linked to biological activities of β-glucans. Natural Product Reports. 2011;28(3):457-66.
26. Yunzhen Zhang , Yueqin Li , Qiang Xia , Lianliang Liu , Zufang Wu , Daodong Pan. Recent advances of cereal β-glucan on immunity with gut microbiota regulation functions and its intelligent gelling application.Crit Rev Food Sci Nutr. 2023;63(19):3895-3911.
27. Apurva Singla,Om Prakash Gupta,Vijeta Sagwal, Abhishek Kumar, Neha Patwa,Narender Mohan, Ankush,Dinesh Kumar, Om Vir, Jogendra Singh, Lokendra Kumar, Chuni Lal and Gyanendra Singh. Beta-Glucan as a Soluble Dietary Fiber Source: Origins, Biosynthesis, Extraction, Purification, Structural Characteristics, Bioavailability, Biofunctional Attributes, Industrial Utilization, and Global Trade. Nutrients 2024, 16(6), 900.
28. Hongwei Cao, Ranqing Li , Mengmeng Shi , Hongdong Song , Sen Li , Xiao Guan Promising effects of β-glucans on gelation in protein-based products: A review. Int J Biol Macromol. 2024 Jan;256(Pt 2):127574.
29. Great Iruoghene Edo , Winifred Ndudi , Raghda S. Makia , Irene Ebosereme Ainyanbhor, Emad Yousif , Tayser Sumer Gaaz , Khalid Zainulabdeen , Agatha Ngukuran Jikah , Rapheal Ajiri Opiti , Patrick Othuke Akpoghelie , Joseph Oghenewogaga Owheruo , Arthur Efeoghene Athan Essaghah , Huzaifa Umar. Beta-glucan: An overview in biological activities, derivatives, properties, modifications and current advancements in food, health and industrial applications. Process Biochemistry. Volume 147, December 2024, Pages 347-370.
30. Junying Bai , Yikai Ren , Yan Li, Mingcong Fan , Haifeng Qian , Li Wang , Gangcheng Wu , Hui Zhang , Xiguang Qi , Meijuan Xu , Zhiming Rao. Physiological functionalities and mechanisms of *β*-glucans. Trends in Food Science & Technology, Volume 88, June 2019, Pages 57-66
31. Chunhua Chen , Xiaojun Huang , Hui Wang , Fang Geng , Shaoping Nie. Effect of β-glucan on metabolic diseases: a review from the gut microbiota perspective. Current Opinion in Food Science. Volume 47, October 2022, 100907
32. Wang Q., Ellis P.R. Oat β-glucan: Physico-chemical characteristics in relation to its blood-glucose and cholesterol-lowering properties. Br. J. Nutr. 2014;112:S4–S13
33. Rgia A Othman , Mohammed H Moghadasian, Peter Jh Jones. Cholesterol-lowering effects of oat β-glucan, Nutr Rev. 2011 Jun;69(6):299-309.
34. Thomas Ms Wolever , Maike Rahn , ElHadji Dioum , Susan E Spruill , Adish Ezatagha, Janice E Campbell , Alexandra L Jenkins , YiFang Chu. An Oat β-Glucan Beverage Reduces LDL Cholesterol and Cardiovascular Disease Risk in Men and Women with Borderline High Cholesterol: A Double-Blind, Randomized, Controlled Clinical Trial. Nutr. 2021 Sep 4;151(9):2655-2666.
35, High molecular weight oat β-glucan enhances lipid-lowering effects of phytosterols. A randomised controlled trial.Ferguson JJ, Stojanovski E, MacDonald-Wicks L, Garg ML.Clin Nutr. 2020 Jan;39(1):80-89
36. Emma J Murphy, Emanuele Rezoagli , Ian Major , Neil J Rowan , John G Laffey. β-Glucan Metabolic and Immunomodulatory

Properties and Potential for Clinical Application. J Fungi (Basel). 2020 Dec 10;6(4):356.

37. Xiao Li Shen , Tao Zhao , Yuanzhong Zhou , Xiuquan Shi , Yan Zou , Guohua Zhao. Effect of Oat β-Glucan Intake on Glycaemic Control and Insulin Sensitivity of Diabetic Patients: A Meta-Analysis of Randomized Controlled Trials. Nutrients. 2016 Jan 13;8(1):39.
38. Helen S Goodridge, Andrea J Wolf ,David M Underhill. β-glucan Recognition by the Innate Immune System. Immunol Rev. 2009 Jul;230(1):38–50.
39. Anna Ciecierska1, Małgorzata Ewa Drywień1, Jadwiga Hamulka1, Tomasz Sadkowski Rocz Panstw Zakl Hig Nutraceutical Functions Of Beta-Glucans. 2019;70(4):315-324
40. Helen S Goodridge , Andrea J Wolf , David M Underhill. β-glucan Recognition by the Innate Immune System. Immunol Rev. Immunol Rev. 2009 Jul;230(1):38–50.
.41. Yazhuo Zhang , Xinning Liu , Jun Zhao , Jie Wang , Qiaoling Song , Chenyang Zhao. The phagocytic receptors of β-glucan. Int J Biol Macromol. 2022 Apr 30:205:430-441.
42. Meng Y., Lyu F., Xu X. Zhang, L. Recent advances in chain conformation and bioactivities of triple-helix polysaccharides. Biomacromolecules. 2020; 21:1653–1677. doi: 10.1021/acs.biomac.9b01644
43.Bin Du , Chengyuan Lin, Zhaoxiang Bian , Baojun Xu. An insight into anti-inflammatory effects of fungal beta-glucan, Trends in Food Science & Technology. Volume 41, Issue 1, January 2015, Pages 49-59
44.Valeria Cognigni , Nicoletta Ranallo , Francesca Tronconi , Francesca Morgese , Rossana Berardi, Potential benefit of β-glucans as adjuvant therapy in immuno-oncology: a review. Explor Target Antitumor Ther. 2021 Apr 30;2(2):122–138.
45.panel Sara Baldassano , Giulia Accardi , Sonya Vasto, Beta-glucans and cancer: The influence of inflammation and gut peptide. European Journal of Medicinal Chemistry, Volume 142, 15 December 2017, Pages 486-492
46. Wani, S.M.; Gani, A.; Mir, S.A.; Masoodi, F.A.; Khanday, F.A. β-Glucan: A dual regulator of apoptosis and cell proliferation. *Int. J. Biol. Macromol.* 2021, *182*, 1229–1237.
47. Chauhan, N.; Tiwari, S.; Iype, T.; Jain, U. An overview of adjuvants utilized in prophylactic vaccine formulation as immunomodulators. Expert Rev. Vaccines 2017, 16, 491–502.
48. Gunjan Maheshwari, Sumathi Sowrirajan, Baby Joseph, Extraction and Isolation of β-Glucan from Grain Sources—A Review. Concise Reviews & Hypotheses in Food Science. 13 June 2017
49. Sandra Milena Vásquez Mejía,Alicia de Francisco and BenjaminM. Bohrer. A comprehensive review on cereal β-glucan: extraction, characterization, causes of degradation, and food application. Critical Reviews in Food Science and Nutrition Volume 60, 2020 - Issue 21
50. S. Sujithra , G. Arthanareeswaran , A.F. Ismail , Wirach Taweepreda. Isolation, purification and characterization of β-glucan from cereals - A review. International Journal of Biological Macromolecules. Volume 256, Part 1, January 2024, 1282.
51. Wenjian Yang and Gangliang Huang. Extraction methods and activities of natural glucans. Trends in Food Science & Technology. Volume 112, June 2021, Pages 50-57
52.Winatta Sakdasri, Panisara Arnutpongchai, Supasuta Phonsavat , Eakarach Bumrungthaichaichan , Ruengwit Sawangkeaw. Pressurized hot water extraction of crude polysaccharides, *β*-glucan, and phenolic compounds from dried gray oyster

mushroom. LWT. Volume 168, 1 October 2022, 113895

53. Sujithra, S., Arthanareeswaran, G., Ismail, A.F., Taweepreda, W. Isolation, purification and characterization of β-glucan from cereals - A review. 2024 international Journal of Biological Macromolecules
54. Ó. Benito-Román , E. Alonso , L. Palacio , P. Prádanos , M.J. Cocero. Purification and isolation of β-glucans from barley: Downstream process intensification. Chemical Engineering and Processing: Process Intensification. Volume 84, October 2014, Pages 90-97
55. Vetvicka, V., & Vetvickova, J. Beta-glucan and its effects on immune reactions. *Annals of Translational Medicine*, (2011). 1(1), 5.
56. Pedro Sousa, Diana Tavares-Valente, Manuela Amorim , João Azevedo-Silva , Manuela Pintado, João Fernandes .β-Glucan extracts as high-value multifunctional ingredients for skin health: A review. Carbohydrate Polymers, 15, 2023, 121329