Food and Nutrition Sciences, 2023, 14, 963-983
https://www.scirp.org/journal/fns
ISSN Online: 2157-9458
ISSN Print: 2157-944X

β-Glucans: Characterization, Extraction Methods, and Valorization

Ana Chioru, Aurica Chirsanova

Department of Food and Nutrition, Technical University of Moldova, Chisinau, Republic of Moldova
Email: aurica.chirsanova@toap.utm.md

How to cite this paper: Chioru, A. and Chirsanova, A. (2023) β-Glucans: Characterization, Extraction Methods, and Valorization. *Food and Nutrition Sciences*, **14**, 963-983.
https://doi.org/10.4236/fns.2023.1410061

Received: June 29, 2023
Accepted: October 28, 2023
Published: October 31, 2023

Abstract

β-glucans are bioactive compounds with a wide range of biological properties, including anticancer, anti-inflammatory, antioxidant, and immune-modulating properties. Due to their specific physical properties, such as (in)solubility, viscosity, and gelation, β-glucans are increasingly being used in the food, pharmaceutical, and cosmetic industries. The purpose of this review is to provide an overview of the different types of β-glucans, their sources, especially Saccharomyces cerevisiae yeasts, and the methods of extraction, isolation, and purification of β-glucans, with the aim of optimizing these methods for the efficient production process. Moreover, the physico-chemical properties, modifications, current applications and future prospects of the use of β-glucans in food, medicines, cosmetics and other potential value-added products are summarized. The data presented indicate that β-glucans will play an increasingly important role in the sector of special-purpose food products as well as in other current and future areas.

Keywords

β-Glucans, Yeast, Extraction, Valorization, Value-Added Products

1. Introduction

β-glucans are polymers of glucose with different glycosidic bonds [1]. Most β-glucans play a crucial role in the structure of the cell wall, while others are used as an energy source for metabolism [2]. Despite their simple monosaccharide composition, glucans exhibit a high structural variability [2]. β-glucans are recognized as biologically active substances with immunomodulatory [3] [4], antioxidant [5], anti-inflammatory [6], antitumor [7], cholesterol [8] and glucose [9] lowering properties. In addition, β-glucans are used in the food industry for the production of functional food products [10] and nutraceuticals [11] [12].

In recent decades, β-glucans have gained increasing attention from scientists, with a particular focus on identifying potential β-glucan sources and valorizing agro-food waste. In this context, the Republic of Moldova, being an agrarian country, has a wide variety of agro-food residues that can be utilized [13]. All of these studies have been significant because, at the initiative of the German company Leiber GmbH, β-glucans were recognized as a new food ingredient at the European level in 2017. Thus, studying the applicability and specific functionality in different branches is very topical.

Carbohydrates are widely used as food for humans and animals. In the food industry, they are used to produce alcoholic beverages, as food additives, and in the pharmaceutical industry. Vegetable carbohydrates present in foods consumed by humans and animals contain polymer-like fibers. Thus, there are two types of dietary fiber, soluble and insoluble, which are distinguished by their solubility in water. Insoluble fibers (cellulose, lignin, and some hemicelluloses) are insoluble in water, while soluble fibers (hemicelluloses and pectin) form viscous solutions in water. β-glucans are polysaccharides that can be classified into the hemicellulose group [14].

Although beta-glucans have been studied extensively, their multiple health-promoting effects are still being investigated, including their effects on the skin [15]; the human gut [16], as well as the gut of pigs [17], fish [18] [19], and other animals; the kidneys [20] [21]; the gallbladder [22] [23]; the liver [24]; the brain [25] [26]. The most common sources of beta-glucans are cereals and microorganisms. Beta-glucans are known for their unique immunomodulation properties through their ability to interact with macrophages, triggering a specific beneficial immune response and enhancing the activity of the immune system without overactivation. They have been suggested as vaccine adjuvants for COVID-19. Additionally, they are considered to be safer on the basis of nutritional supplements [27].

However, the review of the production, physical properties, and industrial applications of β-glucans from other promising sources has received little attention and needs further and more in-depth study. The purpose of this work is to provide an overview based on published scientific data. We have also presented the physical properties of β-glucans. Finally, we have included the potential applications of β-glucan in food, cosmetics, the pharmaceutical industry, and other health products.

2. General Description of β-Glucans

2.1. Legal Provisions

According to the document published by EFSA (European Food Safety Authority) in 2011, "Scientific Opinion on the safety of 'beta-glucans from yeast' as a new food ingredient", β-glucans have been recognized as safe products that can be used in both soluble and insoluble forms. For dietary supplements or foods intended for special nutritional uses, a daily dose of 375 mg to 600 mg is recommended [28]. Following this opinion, the European Union adopted Decision (EU) 2017/2048 in 2017, which extended the use of β-glucans from yeast S. cerevisiae to other foods, such as juices (1.3 g/kg), breakfast cereals (15.3 g/kg), biscuits (6.7 g/kg), milk powder (25.5 g/kg), and dairy products (3.8 g/kg). This decision of the European Union was revised in 2019, and the necessary purity of β-glucans was added, which must be greater than 80%. Similarly, more products in which the use of β-glucans is allowed have been added, such as: cereal bars, fermented dairy products, soups, chocolate and sweets, jam, marmalade, and other spreadable fruit products [1] [29].

2.2. Classification of β-Glucans

β-glucans can be classified by their structure and source of origin, and these are interdependent. Based on their origin, β-glucans are divided into cereal and non-cereal β-glucans. In cereals, β-glucans are predominantly found in barley and oats. Other rich sources of β-glucans include mushrooms, seaweed, bacteria, and seafood. β-glucans in cereals have a different structure than non-cereal β-glucans [30].

β-glucans can also be classified by their structure. Ruiz-Herrera [31] classified β-glucans into seven categories based on their structure:

- Non-branched 1,3-β-glucans;
- 1,3-β-glucans with a few branches;
- 1,6-β-glucans formed from a single glucose unit;
- β-glucans containing 1,3 and 1,4 glucose fragments;
- β-glucans formed from 1,3, 1,4, and β 1,6 glucose fragments
- 1,3-β-glucans phosphorylated;
- 1,3-β-glucans with significant 1,6 branching;
- β-glucans formed predominantly from 1,6-linked glucose units.

This classification is based on the type of linkages between the glucose molecules in the β-glucan chain. Non-branched 1,3-β-glucans are the simplest type of β-glucans. They are long, straight chains of β-glucose molecules linked by 1,3-β linkages. Other types of β-glucans have more complex structures. For example, 1,3-β-glucans with a few branches have 1,3-β linkages between most of the glucose molecules, but some of the glucose molecules are linked by 1,6-β linkages. The structure of β-glucans affects their properties, such as their solubility and ability to form gels [31]. The nutritional value of β-glucans from different sources varies depending on the source and the processing method [32]. Therefore, the structure of b-glucans will also influence the digestibility of β-glucans. In general, β-glucans have been shown to be more resistant to digestion in the small intestine, which allows them to reach the large intestine, where they can be fermented by beneficial bacteria [33]. The fermentation of β-glucans by beneficial bacteria produces short-chain fatty acids [34].

2.3. Sources of β-Glucans

As mentioned, the structure of β-glucans presents significant differences based on their sources. **Table 1** shows different types of β-glucans from different sources. Cereal β-glucans from different sources vary in their tri- to tetramer ratio, the share of longer cellulosic fragments and the ratio between two types of glycosidic bonds. The main source of various structural types of glucans is fungal cell walls, which consist mainly of structural polysaccharides and glycoproteins. These β-glucans commonly have trivial names according their fungal origin (grifolan, lentinan, pachyman, pleuran, schizophylan, scleroglucan, etc.) [2]. The yeast-derived beta-(1→3)(1→6)-glucan purportedly has greater biological activity than the (1→3)(1→4)-counterparts [14]. Cereals are considered as the most common β-glucans source, so the unbranched β-glucans are currently more widely used [35].

2.4. The Structure of β-Glucans

Depending on the interchain linkage, glucans are divided into α and β glucans. In general, some α glucans are amorphous and soluble in hot water and play the role of energy storage material. Examples of these are glycogen in fungi and animals, and starch in algae and plants. Those present in the walls of fungi are insoluble in water. Most β-glucans are insoluble in water and almost all solvents, they are mostly crystalline. Examples of β-glucans are cellulose in plants and various 1,3 β-glucans in yeasts [31]. **Figure 1** shows the basic, simple units of β-glucans. All β-glucans are homo-polysaccharides and essentially composed of glucose units linked together and thus have a characteristic 1,3 linked backbone. The structural difference occurs at branching off this backbone, which is dictated by source. β-glucans can be unbranched or branched [30].

β-glucans in cereals consist of a mixture of β-(1,3) and β-(1,4) glycosidic linkages, without branching. Cereal derived β-glucans are generally located in the aleurone (proteins stored as granules), in the sub-aleurone or in the cell wall of endospores, which are all located in oat, barley, wheat [37]. **Figure 2** shows the basic structure of cereal β-glucans.

Whereas, non-cereal β-glucans do not have β-(1,4) linkages. For example, β-glucans in mushrooms are formed from linear β-(1,3) glycosidic linkages with a single β-(1,6) branching linkage every third linear linkage. β-glucans in the cell wall of the yeast Saccharomyces cerevisiae are a large molecule, consisting of linear chains made up of 30 simple β-(1,3) glycosidic units, the chains are linked together by branched β-(1,6) glycosidic linkages. Approximately 60% of the β-d-glucans in yeasts have a long chain of 1500 glucose residues linked by β-(1-3)-glycosidic linkages, and a molecular weight of approximately 100 - 200 kDa [28]. **Figure 3** shows the comparative structure of glucans from mushrooms and yeasts.

The conformation of polysaccharides is determined by the interplay of intermolecular and intramolecular forces, such as hydrogen bonds. Polysaccharides can exist in a variety of conformations, including single helices, double helices, triple helices, random coils, aggregates, rod-like structures, and worm-like structures [10].

Table 1. Sources of β-glucans.

Name of β-glucan	The source of provenance of β-glucan		Literature				
	Source		Title	Authors	Journal of Publication	Publication Year	References
$(1\to3)$-β-D-glucan	Bacterias Seaweeds Lichens	Agrobacterium, Rhizobium, Cellulomonas, Bacillus, Alcaligenes faecalis Euglena, Astasialonga, Pavlovamesolychnon Stereocaulonramulosum, Ramalina, Cladonia	Chemistry, physico-chemistry and applications linked to biological activities of β-glucans β-Glucan in Foods and Its Physiological Functions	Barsanti L, Passarelli V, Evangelista V, Nakashima A, Yamada K, Iwata O	Nat Prod Rep Journal of Nutritional Science and Vitaminology	2011 2018	[36] [37]
$(1\to6)$-β-D-glucan	Lichens Fungus	Lasalliapustulata Guignardiacitricarpa	Structural analysis of glucans	Synytsya A, Novak M	Ann Transl Med	2014	[2]
$(1\to3)(1\to2)$-β-D-glucan	Bacterias	Streptococuspneumonie	Chemistry, physico-chemistry and applications linked to biological activities of β-glucans	Barsanti L, Passarelli V, Evangelista V	Nat Prod Rep	2011	[36]
$(1\to3)(1\to4)$-β-D-glucan	Cereals Lichens Fungus	Barley, Oats, Wheat Cetrariaislandica Calocybe indica	A Concise Review on the Molecular Structure and Function Relationship of β-Glucan Recent advances in enzymatic synthesis of β-glucan and cellulose	Du B, Meenu M, Liu H, Xu B Bulmer GS, de Andrade P, Field RA, van Munster JM	IJMS Carbohydrate Research	2019 2021	[10] [38]
$(1\to3)(1\to6)$-β-D-glucan	Fungus Seaweeds Bacterias	Lentinula edodes, Grifolafrondosa, Schizophyllan commune, Sclerotium, Pleurotusostreatus, Botryosphaeria, Saccharomyces cerevisae, Schizosaccharomyces pombe, Aspergillus fumigatus, Candida albicans, Aspergillus oryzae Chaetcerosmulleri, Ochromonas, Haramonasdimorpha, Phaeodactylumtricornutum, Xanthomonas campestris, Bacillus natto	A Concise Review on the Molecular Structure and Function Relationship of β-Glucan Structural analysis of glucans Evaluating comparative β-glucan production aptitude of Saccharomyces cerevisiae, Aspergillus oryzae, Xanthomonas campestris, and Bacillus natto β-Glucan in Foods and Its Physiological Functions	Du B, Meenu M, Liu H, Xu B Synytsya A, Novak M Utama GL, Dio C, Sulistiyo J, Nakashima A, Yamada K, Iwata O	IJMS Ann Transl Med Saudi Journal of Biological Sciences Journal of Nutritional Science and Vitaminology	2019 2014 2021 2018	[10] [2] [39] [37]
$(1\to4)(1\to6)$-β-D-glucan	Fungus	Auricularia auricula-judae, Coriolusversicolor	Chemistry, physico-chemistry and applications linked to biological activities of β-glucans	Barsanti L, Passarelli V, Evangelista V,	Nat Prod Rep	2011	[36]

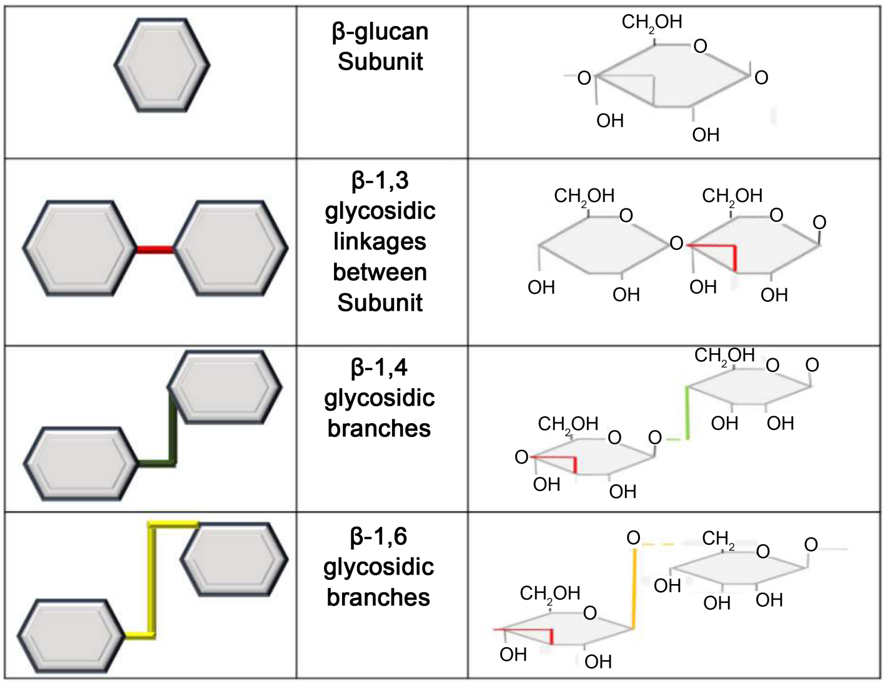

Figure 1. The structure of β-glucans [30].

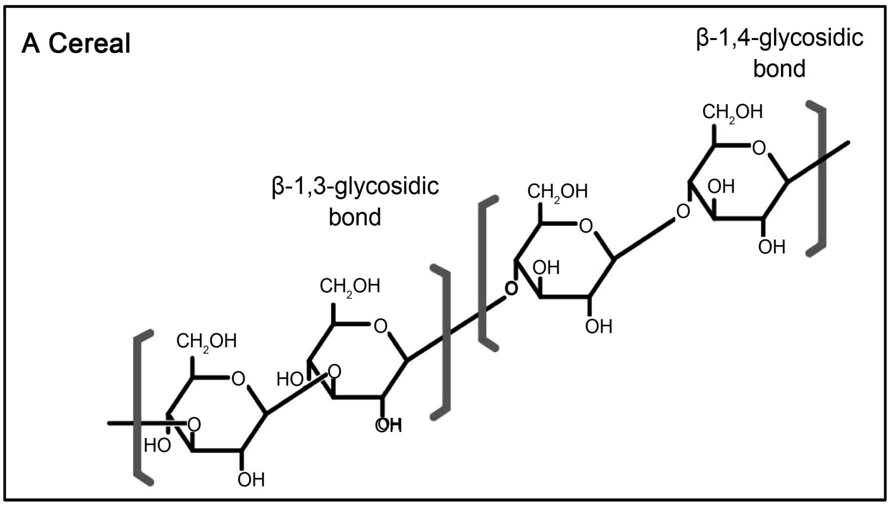

Figure 2. The structure of β-glucans from cereals [33].

2.5. Properties of β-Glucans

2.5.1. Solubility of β-Glucans

The solubility of β-glucans is a critical factor that determines their functional properties, such as stability, emulsifying capacity, and membrane formation [10]. β-glucans in the cell wall are classified into 3 categories based on solubility: water-soluble (1→6 β-glucans, short polymers), alkali-soluble (1→3 β-glucans not linked to chitin), and alkali-insoluble (1→3, 6 β-glucans and linked to chitin) [40]. β-glucans are very hydrophilic due to the abundance of hydroxyl groups that participate in hydrogen bonds with water, giving the molecule the ability to retain water in both soluble and insoluble forms [41]. A study carried out by

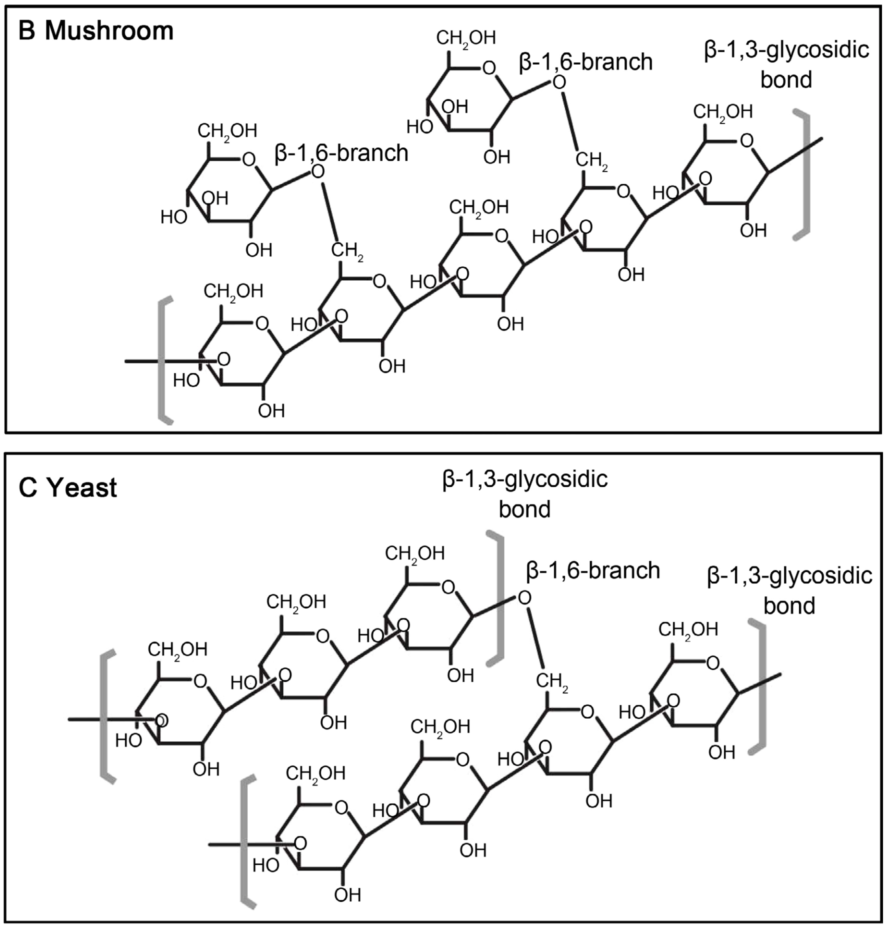

Figure 3. Structure of β-glucans from fungi and yeasts [33].

Kim, H.J. showed that β-glucan from oats with molecular weight between 2.42 × 105 and 1.61 × 105 g/mol has the highest water solubility of 83.4% to 87.3% [42]. Another study reported that an increase in the molecular weight of oat β-glucan from 1.13 × 105 to 9.04 × 105 g/mol and from 1.65 × 105 to 8.51 × 105 g/mol leads to a significant decrease in its solubility in water from 72.8% to 68.2% and 72.3% to 67.2%, respectively [43]. A method for reducing the molecular weight of β-glucans and increasing their solubility is sulfation. The incorporation of ionic groups increases the amount of small β-glucan fragments.

2.5.2. Rheological Properties of β-Glucans

The water retention capacity and mode of water retention of β-glucans are influenced by several factors, including: structure, purity, extraction method, and isolation method. β-glucans are a type of dietary fiber that forms a viscous solution when mixed with water [44]. In aqueous solutions, β-glucans have a high viscosity due to their high molecular weight, conformation, and interactive properties [45]. The study conducted by Petravić-Tominac demonstrated that the rheological properties of β-glucans are influenced by the extraction and drying methods used to obtain them [46]. Due to their rheological properties, β-glucans can be used in the food industry as thickeners, texture enhancers, stabilizers, and fortified ingredients.

2.6. *β*-Glucans from the Cell Wall of the Yeast *Saccharomyces cerevisiae*

Saccharomyces cerevisiae is a non-pathogenic, non-toxic yeast that is commonly used in fermentation processes. It produces *β*-glucans, which are a component of its cell wall [47]. The earliest studies of the structure of fungal glucans were made with those produced by *S. cerevisiae* secreted during protoplast regeneration. *Saccharomices cerevisiae* yeasts have a thick cell wall composed of polysaccharides and proteins that protect the inner compartments of the cell. The most abundant polysaccharide in the yeast cell wall is *β*-glucan, which constitutes 65% - 90% of the total polysaccharides [31]. The cell wall of these yeasts is composed of 55% *β*-glucans with 1,3 linkages and 12% 1,6 *β*-glucans. In total, the mixture of 1,3 and 1,6 *β*-glucans constitutes between 9% and 18% of the yeast cell mass [48].

The cell wall of *S. cerevisiae* yeasts represents 15% - 30% of the dry weight of the cell, and has a thickness of 105 - 200 nm [49]. The cell wall is composed of 40% manoproteins, 60% *β*-glucans, and a small amount of chitin. The composition and organization of the cell wall vary at different stages of the cell cycle [50]. The process of glucan formation takes place in the plasma membrane [51]. Structurally, manoproteins are linked indirectly to *β*-1,6-glucan via a glycosylphosphatidylinositol (GPI) anchor and directly to *β*-1,3-glucan. This outer part of the cell wall, with a thickness of 30 - 40 nm, contains a protein fragment that can be partially removed chemically, while the rest of the cell wall requires enzymatic treatment [1]. The schematic representation of the yeast cell wall and distribution of *β*-glucans in *Saccharomices cerevisiae* is shown in **Figure 4**.

β-glucans in the cell wall of yeasts, unlike plant cell walls, are 80% - 85% insoluble in hot alkalis, due to covalent association with chitin and other polysaccharides [1]. Following the isolation of *β*-glucans from yeasts, there is co-isolation of glycogen, an *α*-1,4-glucan similar to starch. The removal of glycogen, in order to obtain the most accurate results, is difficult [52].

3. Methods of the Extraction of *β*-Glucans from Yeasts

The extraction of *β*-glucans from the cell wall of Saccharomyces cerevisiae consists of two steps: 1). Cell disruption: *β*-glucan is located in the cell wall, so it is necessary to lyse the cells and separate the insoluble cell wall from the cytoplasm; 2). Extraction of *β*-glucan from the insoluble cell wall [49]. To be used as a drug, *β*-glucan must be biologically active and soluble in water. Numerous studies have focused on transforming *β*-glucan into a water-soluble form through chemical modifications [53]. Molecular modifications of *β*-glucans can affect their structure and molecular weight, with a significant impact on their bioactivity. To date, several molecular modification methods have been developed, including carboxymethylation, phosphorylation, sulfation, ultrasonic disruption,

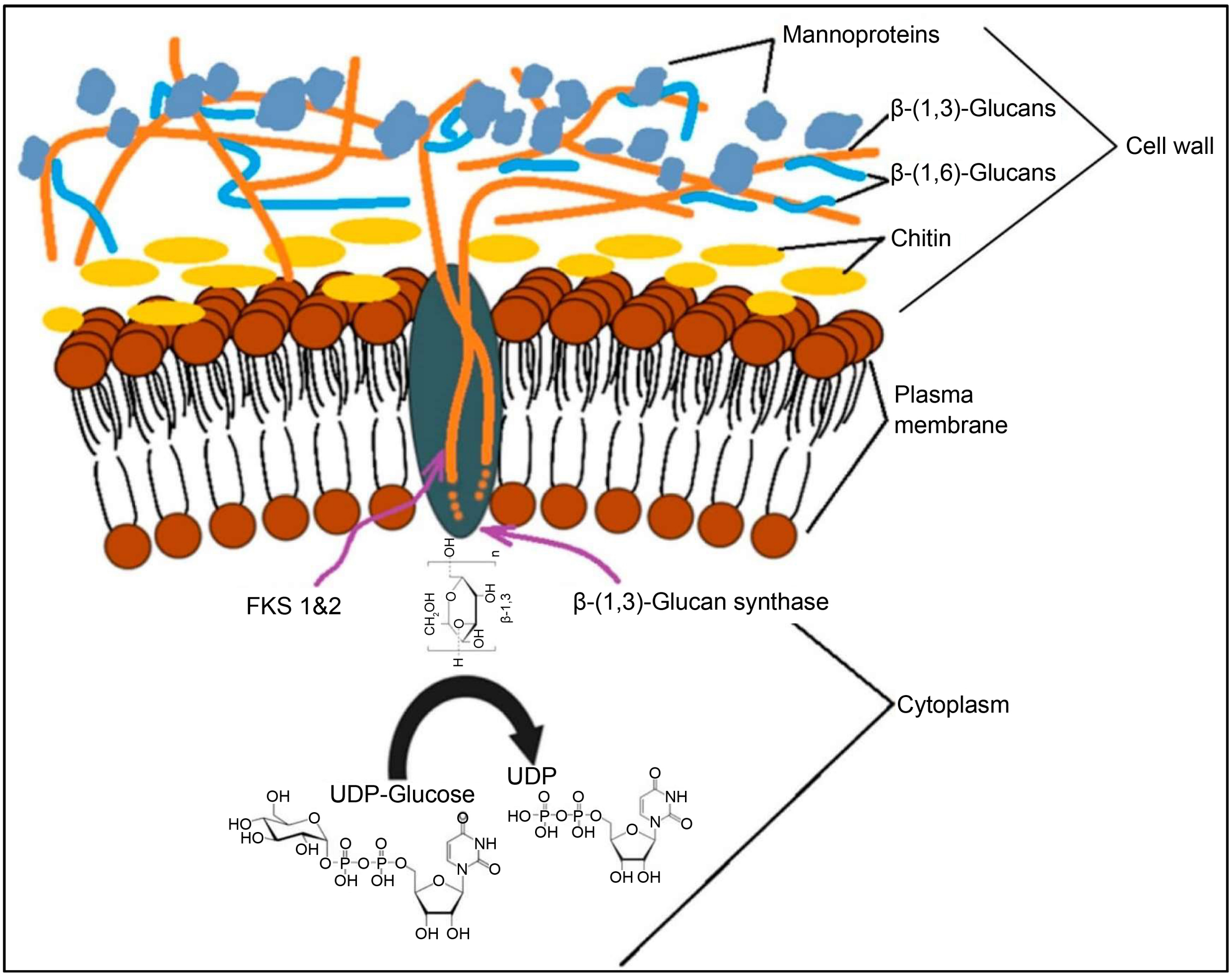

Figure 4. Schematic representation of the yeast cell wall and distribution of β-glucans in Saccharomyces cerevisiae [1].

selenylation, and polysaccharide degradation. Molecular modifications can affect the physical and chemical properties of polysaccharides, such as solubility, molecular weight, and intrinsic viscosity. Modified polysaccharides have superior biological properties [54].

3.1. Mechanical Modification

This method consists of molecular modification by mechanical action, causing the rupture of the main chain of the glucan macromolecule, which will lead to the solubilization and functionalization of the polysaccharide, without destroying the basic molecular structure of the yeast β-glucan. By this method, fractions of β-glucans with a lower molecular weight, better water solubility, and modification of the conformation in solutions are obtained. This method is more efficient when used in combination with other methods.

3.2. Thermal Degradation

Thermal degradation of β-glucans is a simple method for reducing their molecular weight. In 2018, a study was conducted [55] that involved thermal degradation of yeast β-glucan for solubilization. It was found that it was efficiently solubilized after being treated in an aqueous suspension at 135˚C for several hours. Another study conducted in 2022 involved autolysis-extraction with warm water (50˚C for 48 h.) and treatment at 121˚C for 6 hours in an autoclave for the extraction of fresh β-glucan [56].

3.3. Irradiation

Irradiation of β-glucans leads to their physicochemical modification. The application of ionizing radiation, such as gamma rays, X-rays, and electron beams, leads to a significant decrease in the molecular weight of β-glucans, depending on the radiation dose. Additionally, irradiation improves the solubility and decreases the viscosity of β-glucans [54].

3.4. The Treatment with Ultrasound

This method involves treating with low-frequency and high-intensity ultrasound, which leads to depolymerization and breakage of the side chain of the molecules. Following this treatment, the molecular weight of the polysaccharides also decreases, the viscosity decreases, and the solubility in water increases [57]. A study from 2022 showed that ultrasound-assisted H_2O_2 treatment is a simple and efficient method for reducing the molecular weight and increasing the solubility of yeast β-glucans [58].

3.5. Chemical Modification

Chemical modification is the most commonly used method, as it can significantly increase the solubility in water and respective bioactivity of polysaccharides. The most common chemical modification methods are sulfation, alkylation, carboxymethylation, phosphorylation, selenization, and acetylation [41].

3.6. Sulfation

Sulfated polysaccharides are synthesized by replacing hydroxyl, carboxyl, or amino terminal groups with sulfate groups, with improved biological activities. The solubility of the modified glucan is increased due to the hydrophilicity of the sulfate group. The good aqueous solubility of the resulting polysaccharide has represented a huge progress in its application, especially in pharmaceutical products.

3.7. Carboxymethylation

Carboxymethylation is used to increase the water solubility of macromolecular polysaccharides, such as cellulose, scleroglucan, and chitin. To prepare carboxymethylated polysaccharides, chloroacetic acid or sodium monochloroacetate is used as a substrate, reacting with polysaccharides in basic 2-propanone.

3.8. Phosphorylation

Phosphorylation is a method by which a phosphate group is introduced into a polysaccharide. Several studies have shown that both naturally occurring and artificially modified phosphorylated polysaccharides have specific medicinal properties. The presence of charged phosphate groups can lead to improved water solubility, changes in molecular weight, and changes in the conformation of the polysaccharide chain [41].

3.9. Biological Modification - Enzymatic

Biological modification of polysaccharides refers specifically to enzymatic modification, which consists in the degradation of *β*-glucans due to the catalysis of enzymes. Compared to chemical modification, this is a gentler and promising method, due to its high specificity and efficiency. The most used enzymatic modification is depolymerization, used especially in industry [54].

Numerous studies have shown that both the extraction method and the drying method of yeasts play a crucial role on their properties. The most common methods for extracting *β*-glucans from yeasts are: acid extraction, alkaline extraction, combined acid-base extraction, enzymatic extraction, and enzymatic-alkaline extraction [59]. For example, acid-base extraction can be performed using different reagents: NaOH/HCl extraction, NaOH/CH_3COOH extraction, NaOH/NaClO extraction, and NaClO/DMSO extraction [32]. Alkaline extraction involves treatment with a 6% NaOH solution (g/v) at 90˚C for 2 hours, followed by centrifugation [60]. Several studies have shown that certain characteristics, such as the physicochemical parameters, chemical structure, and molecular weight of *β*-glucans, determine how they will interact with the immune system [52]. The most appropriate extraction method depends on the sources and the structures of *β*-glucans. The cost of *β*-glucans production is influenced by several factors, including the source of the beta glucans, the desired purity and properties of the final product, and the scale of production. Oats are a relatively inexpensive source of beta glucans, and they can be processed using relatively simple methods. Another way to reduce costs is to optimize the extraction process. For example, the extraction temperature and pH can be adjusted to optimize the yield and purity of the beta glucans. Additionally, the use of enzymes and other additives can help to improve the efficiency of the extraction process [32] [61]. The list of the most widespread methods of methods of extraction and analysis of *β*-glucans is presented in **Table 2**.

4. Valorization of *β*-Glucans in Industrial Practice

The growing awareness of the potential of some food components to protect people against different diseases has led to an increased demand for functional foods. As a result, consumers are increasingly looking for natural foods that are safe, attractive, and provide valuable nutrients that can help to improve human health and contribute to a healthy lifestyle. This trend presents a challenge for food scientists, whose task is to develop and identify sources of foods with specific properties that can improve health.

Table 2. Methods of extraction and analysis of β-glucans.

Source of β-glucan	Extraction method	Analysismethod	Literature				
			Title	Authors	Journal of Publication	Publication Year	References
Saccharomyces cerevisiae dry yeast cells	-The acid-base extraction method (NaOH, 80˚C, 2 h, CH_3COOH)	Spectroscopicanalysis FTIR	Enhancement of β-Glucan Biological Activity Using a Modified Acid-Base Extraction Method from Saccharomyces cerevisiae.	Mahmoud Amer E, Saber SH, Abo Markeb A,	Molecules	2021	[62]
			Biotechnological β-glucan Production from Returned Baker's Yeast and Yeast Remaining after Ethanol Fermentation	Zohri AE-N, Moubasher H, Abdel-Hay H, Orban M	Egyptian Sugar Journal	2019	[63]
Saccharomyces cerevisiae pure culture	-Modified acid-base extraction method (NaOH, 80˚C, 2 h, DMSO)	Spectroscopic analysis FTIR	Extraction of β-glucan from Saccharomyces cerevisiae: Comparison of different extraction methods and in vivo assessment of immunomodulatory effect in mice	Pengkumsri N, Sivamaruthi BS, Sirilun S,	Food Sci Technol	2016	[64]
Saccharomyces cerevisiae, pure culture NRRL Y-567	-Alkaline-acid extraction method assisted with ultrasound (NaOH, 90˚C, 1 h, 40 kHz during 15 min, CH_3COOH, 85˚C, 1 h, -Ultrasound-assisted autolysis (50˚C, 24 h, 40 kHz during 15 min, CH_3COOH, 85˚C, 1 h	Spectroscopic analysis FTIR	A new isolation method of β-d-glucans from spent yeast Saccharomyces cerevisiae	Liu X, Wang Q, Cui S, Liu H	Food Hydrocolloids	2008	[65]
Saccharomyces cerevisiae residual yeasts from beer production	-Induced autolysis (3% NaCl, 55˚C, 24 h) + treatment with water and organic solvent (121˚C, 4 h), homogenization and protease hydrolysis	Electron microscopy	Optimized methodology for extraction of (1 → 3)(1 → 6)-β-d-glucan from Saccharomyces cerevisiae and in vitro evaluation of the cytotoxicity and genotoxicity of the corresponding carboxymethyl derivative	Magnani M, Calliari CM, de Macedo FC	Carbohydrate Polymers	2009	[66]
			Application of different methods for the extraction of yeast β-glucan	VassileiosVarelas, P. Tataridis, M. Liouni, T. Nerantzis	e-Journal of Science & Technology	2016	[67]

Continued

Saccharomyces cerevisiae VIN 13 S	-Enzyme treatment + NaOH -Induced autolysis (3% NaCl), hot water extraction, sonication, extraction of lipids and proteins with the help of enzymes	Enzymatic assay kit (Megazyme International)	Effect of preparation methods on physiochemical and functional properties of yeast β-glucan	Fu W, Zhao G, Liu J	LWT	2022	[56]
Saccharomyces cerevisiae dry yeast cells Angel Yeast Co., Ltd (China)	-Autolysis (55˚C, 48 h), hot water extraction (121˚C, 6 h), deproteinization treatment (proteases)	Enzymatic assay kit (Megazyme International)	Enzymatic process for the fractionation of baker's yeast cell wall (Saccharomyces cerevisiae)	Borchani C, Fonteyn F, Jamin G	Food Chemistry	2014	[68]
Saccharomyces cerevisiae cell wall in the form of powder	-Extraction by the enzymatic method (hot water extraction 125˚C, 5 h, treatment with proteases, treatment with lipases)	Enzymatic assay kit (Megazyme International)	New method for preparing purity β-D-glucans (beta-Glucan) from baker's yeast (Saccharomyces cerevisiae)	Khanh Pham, Nguyen Nhut, Nguyen Cuong	STDJ	2020	[69]
Saccharomyces cerevisiae baker's yeast powder Saf-Viet	-Extraction using the ionic solution (ionic solution 1-butyl-3-methyl-imidazolium Chloride, stirring 30 min at 80˚C)	1D- and 2D-NMR spectroscopy	Optimization of β-glucan extraction from waste brewer's yeast saccharomyces cerevisiae using autolysis, enzyme, ultrasonic and combined enzyme – ultrasonic treatment	Tran Minh Tam, Nguyen Quoc Duy	American Journal of Research Communica-tion	2013	[70]
Saccharomyces cerevisiae residual yeasts from beer production	-Combined enzymatic and ultrasound extraction	Enzymatic assay kit (Megazyme International)	A Simple and Efficient Mechanical Cell Disruption Method Using Glass Beads to Extract β-Glucans from Spent Brewer's Yeast	Avramia I, Amariei S	Applied Sciences	2022	[71]
Saccharomyces cerevisiae residual yeasts from beer production	-Mechanical damage of yeast cells, acid-base extraction	Spectroscopicanalysis FTIR	Antioxidant Activity of β-Glucan	Kofuji K, Aoki A, Tsubaki K	ISRN Pharmaceutics	2012	[72]

This review focused on the potential for the utilization of β-glucans -an important ingredient for the development of new products in the food industry. Over time, the immunomodulatory activity of various polysaccharides, either from plants or microorganisms, has been observed. β-glucans belong to this group. Generically, these are called biological response modifiers (BRM) [73],

[74]. In addition, various studies have shown that β-glucans also have other therapeutic properties in the human body, such as antioxidant activity [75] [76] hypoglycemic [44] [77] [78], hypolipidemic (reduction of lipid content) [79] [80], prebiotic activity [59] [81], antitumor action [82] [83] reduces inflammation in acute respiratory infections, including in the case of covid-19 [84]. Therefore, β-glucans can be added to products as a dietary supplement in: juices, cereal bars, breakfast cereals, biscuits, dairy products, chocolate, soups, sauces, and powdered milk.

In addition to their therapeutic effects, β-glucans can be used in the food industry as functional ingredients: thickener, water retention agent, texturizer, stabilizer, emulsifier and fat substitute [85]. Numerous studies show that β-glucans show positive results used in different products as functional agents. The study carried out by Mykhalevych [40] regarding the use of β-glucans in dairy products showed that in dairy drinks with additions it is possible to replace carrageenans with β-glucans, for example in a drink based on orange juice the addition of 0.5% of barley β-glucans and 1.5% whey protein isolate, the drink becomes more structured, less acidic. Another study published by Chiozzi [35] reports that the addition of 0.6% oat β-glucan in fermented dairy products does not affect the fermentation time and leads to an increase in the viscosity of the product. In sausages, a 10:1 mixture of oat β-glucan and marine collagen peptides allows the replacement of 50% of fats. Study conducted by Ramandeep Kaur [86] demonstrates the positive effect of β-glucans on the rheological, physicochemical, sensory properties of yogurt, effects that are maintained during the storage period of the product compared to the control sample. In the same way, β-glucans also improved the nutritional values of yogurt, acting as a prebiotic. It should be noted that the sensory characteristics of yogurt samples with the addition of beta-glucans in different amounts do not influence the smell of yogurts obtained. At the same time, the external appearance and consistency are changed in essentially: the consistency of the curd becomes firmer but still remains without gas bubbles, with poor elimination of whey [87]. Another study shows that bifidobacterial are capable of utilizing all of the structurally diversified β-glucansas a substrate of fermentation comparably to the known prebioticinulin [20].

The use of β-glucans from yeasts was studied by Marinescu G. [88] for the preparation of mayonnaise. In this study, 50% of the oil was replaced with β-glucan, so the added mayonnaise is less caloric and has a more stable storage stability than mayonnaise without β-glucan.

β-glucans can be used in meat products for the partial substitution of carrageenans and starch, this shows the study conducted by Sandra M. Vasquez Mejia [89]. They play the role of stabilizer, water retention agent and lead to the reduction of the curtains during baking. A significant decrease in hardness and fracture values was also observed, while maintaining the structural cohesiveness of the samples, in part due to the increase in moisture content.

5. Conclusion

β-glucans are among the compounds that will be increasingly studied for their potential applications in various industrial sectors. This is supported by the scientific studies that highlight their diverse multifunctional properties; by the growing trend of consumers who prefer products with "clean labels" without additives, and by other factors that lead to the development of new functional ingredients, such as β-glucans. Currently, β-glucans have a wide range of applications in the food, pharmaceutical, and cosmetic industries. However, their potential is not yet fully realized. Further research is needed to optimize the extraction, purification, drying, and use of β-glucans from yeast in various fields.

Acknowledgements

The research was made possible by the project: "Valorisation de co-produits vinicole moldaves: identification et caractérisation d'agents multifonctionnels" supported by the Francophone University Agency (AUF), held within the Department of Food and Nutrition, Faculty of Food Technology of the Technical University of Moldova.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Avramia, I. and Amariei, S. (2021) Spent Brewer's Yeast as a Source of Insoluble β-Glucans. *International Journal of Molecular Sciences*, **22**, Article No. 825. https://doi.org/10.3390/ijms22020825

[2] Synytsya, A. and Novak, M. (2014) Structural Analysis of Glucans. *Annals of Translational Medicine*, **2**, Article No. 17. https://doi.org/10.3978/j.issn.2305-5839.2014.02.07

[3] van Steenwijk, H.P., Bast, A. and de Boer, A. (2021) Immunomodulating Effects of Fungal Beta-Glucans: From Traditional Use to Medicine. *Nutrients*, **13**, Article No. 1333. https://doi.org/10.3390/nu13041333

[4] Mirończuk-Chodakowska, I., Kujawowicz, K. and Witkowska, A.M. (2021) Beta-Glucans from Fungi: Biological and Health-Promoting Potential in the COVID-19 Pandemic Era. *Nutrients*, **13**, Article No. 3960. https://doi.org/10.3390/nu13113960

[5] Benlier, N., Uçar, N., Öğüt, E., *et al.* (2022) Assessment of Antioxidant Effect of Beta-Glucan on the Whole BloodOxidative DNA Damage with the Comet Assay in Colorectal Cancer. *CMP*, **15**, 446-453. https://doi.org/10.2174/1874467214666210219145445

[6] Cerletti, C., Esposito, S. and Iacoviello, L. (2021) Edible Mushrooms and Beta-Glucans: Impact on Human Health. *Nutrients*, **13**, Article No. 2195. https://doi.org/10.3390/nu13072195

[7] Choromanska, A., Kulbacka, J., Rembialkowska, N., *et al.* (2015) Anticancer Properties of Low Molecular Weight Oat Beta-Glucan—An *in Vitro* Study. *International Journal of Biological Macromolecules*, **80**, 23-28. https://doi.org/10.1016/j.ijbiomac.2015.05.035

[8] Joyce, S.A., Kamil, A., Fleige, L. and Gahan, C.G.M. (2019) The Cholesterol-Lowering Effect of Oats and Oat Beta Glucan: Modes of Action and Potential Role of Bile Acids and the Microbiome. *Frontiers in Nutrition*, **6**, Article No. 171. https://doi.org/10.3389/fnut.2019.00171

[9] Mio, K., Togo-Ohno, M., Tadenuma, N., *et al.* (2022) A Single Administration of Barley *β*-Glucan and Arabinoxylan Extracts Reduces Blood Glucose Levels at the Second Meal via Intestinal Fermentation. *Bioscience*, *Biotechnology*, *and Biochemistry*, **87**, 99-107. https://doi.org/10.1093/bbb/zbac171

[10] Du, B., Meenu, M., Liu, H. and Xu, B. (2019) A Concise Review on the Molecular Structure and Function Relationship of *β*-Glucan. *International Journal of Molecular Sciences*, **20**, Article No. 4032. https://doi.org/10.3390/ijms20164032

[11] Sinangil, Z., Taştan, Ö. and Baysal, T. (2022) Beta-Glucan as a Novel Functional Fiber: Functional Properties, Health Benefits and Food Applications. *Turkish Journal of Agriculture—Food Science and Technology*, **10**, 1957-1965. https://doi.org/10.24925/turjaf.v10i10.1957-1965.5430

[12] Mohan, S., Abdollahi, S. and Pathak, Y. (2023) Applications of Functional Foods and Nutraceuticals for Chronic Diseases, Safety and Efficacy Determination in Functional Foods and Nutraceuticals. CRC Press, Boca Raton.

[13] Chirsanova, A. and Calcatiniuc, D. (2021) The Impact of Food Waste and Ways to Minimize IT. *Journal of Social Sciences*, **4**, 128-139. https://doi.org/10.52326/jss.utm.2021.4(1).15

[14] Rahar, S., Swami, G., Nagpal, N., *et al.* (2011) Preparation, Characterization, and Biological Properties of *β*-Glucans. *Journal of Advanced Pharmaceutical Technology & Research*, **2**, Article No. 94. https://doi.org/10.4103/2231-4040.82953

[15] Liu, Y., Zhang, J., Tang, Q., *et al.* (2014) Physicochemical Characterization of a High Molecular Weight Bioactive *β*-d-glucan from the Fruiting Bodies of *Ganoderma lucidum*. *Carbohydrate Polymers*, **101**, 968-974. https://doi.org/10.1016/j.carbpol.2013.10.024

[16] Atanasov, J., Schlörmann, W., Trautvetter, U. and Glei, M. (2020) The Effects of *β*-glucans on Intestinal Health. *Ernährungs Umschau*, **67**, 52-59. https://doi.org/10.4455/eu.2020.010

[17] Bearson, S.M.D., Trachsel, J.M., Bearson, B.L., *et al.* (2023) Effects of *β*-glucan on *Salmonella enterica* Serovar Typhimurium Swine Colonization and Microbiota Alterations. *Porcine Health Management*, **9**, Article No. 7. https://doi.org/10.1186/s40813-023-00302-4

[18] Porter, D., Peggs, D., McGurk, C. and Martin, S.A.M. (2023) *In-Vivo* Analysis of ProtecTM and *β*-glucan Supplementation on Innate Immune Performance and Intestinal Health of Rainbow Trout. *Fish & Shellfish Immunology*, **134**, Article ID: 108573. https://doi.org/10.1016/j.fsi.2023.108573

[19] Fino, H.A., Wiegertjes, G. and Kokou, F. (2023) Dietary Effect of *β* Glucans on Nile Tilapia Microbiome and Health.

[20] Ephraim, E. and Jewell, D.E. (2023) Betaine and Soluble Fiber Improve Body Composition and Plasma Metabolites in Cats with Chronic Kidney Disease. *Frontiers in Bioscience* (*Elite Edition*), **15**, Article No. 8. https://doi.org/10.31083/j.fbe1502008

[21] Wu, Z., Yang, Y., Li, J., *et al.* (2023) *β*-Glucans in Particulate and Solubilized Forms Elicit Varied Immunomodulatory and Apoptosis Effects in Teleost Macrophages in a Dose Dependent Manner. *Frontiers in Immunology*, **14**, Article ID: 1243358. https://doi.org/10.3389/fimmu.2023.1243358

[22] Hazra, R. and Roy, D. (2023) Monosaccharide Induced Temporal Delay in Cholesterol Self-Aggregation. *Journal of Biomolecular Structure and Dynamics*, **41**, 3205-3217. https://doi.org/10.1080/07391102.2022.2048076

[23] Chen, L., He, X., Pu, Y., *et al.* (2023) Polysaccharide-Based Biosorbents for Cholesterol and Bile Salts in Gastric-Intestinal Passage: Advances and Future Trends. *Comprehensive Reviews in Food Science and Food Safety*, **22**, 3790-3813. https://doi.org/10.1111/1541-4337.13214

[24] Liu, Q., Tang, Q., Liu, X., *et al.* (2023) The Effect and Mechanism of Highland Barley β-Glucan in Improving Liver Regeneration after Partial Hepatectomy. *Journal of Functional Foods*, **107**, Article ID: 105631. https://doi.org/10.1016/j.jff.2023.105631

[25] Hu, M., Zhang, P., Wang, R., *et al.* (2022) Three Different Types of β-Glucans Enhance Cognition: The Role of the Gut-Brain Axis. *Frontiers in Nutrition*, **9**, Article ID: 848930. https://doi.org/10.3389/fnut.2022.848930

[26] Liu, Z., Liu, Q. and Qi, G. (2023) Editorial: Dietary Polysaccharides and Brain Health. *Frontiers in Nutrition*, **10**, Article ID: 1249498. https://doi.org/10.3389/fnut.2023.1249498

[27] Ikewaki, N., Kurosawa, G., Levy, G.A., *et al.* (2023) Antibody Dependent Disease Enhancement (ADE) after COVID-19 Vaccination and Beta Glucans as a Safer Strategy in Management. *Vaccine*, **41**, 2427-2429. https://doi.org/10.1016/j.vaccine.2023.03.005

[28] EFSA Panel on Dietetic Products, Nutrition and Allergies (NDA) (2011) Scientific Opinion on the Safety of "Yeast Beta-Glucans" as a Novel Food Ingredient. *EFSA Journal*, **9**, 2137. https://doi.org/10.2903/j.efsa.2011.2137

[29] European Parliament and of the Council Commission Implementing Decision (EU) 2017/2078 of 10 November 2017 Authorising an Extension of Use of Yeast Beta-Glucans as a Novel Food Ingredient under Regulation (EC) No. 258/97.

[30] Murphy, E.J., Rezoagli, E., Major, I., *et al.* (2021) β-Glucans. *Encyclopedia*, **1**, 831-847. https://doi.org/10.3390/encyclopedia1030064

[31] Ruiz-Herrera, J. and Ortiz-Castellanos, L. (2019) Cell Wall Glucans of Fungi. A Review. *The Cell Surface*, **5**, Article ID: 100022. https://doi.org/10.1016/j.tcsw.2019.100022

[32] Maheshwari, G., Sowrirajan, S. and Joseph, B. (2017) Extraction and Isolation of β-Glucan from Grain Sources—A Review. *Journal of Food Science*, **82**, 1535-1545. https://doi.org/10.1111/1750-3841.13765

[33] El Khoury, D., Cuda, C., Luhovyy, B.L. and Anderson, G.H. (2012) Beta Glucan: Health Benefits in Obesity and Metabolic Syndrome. *Journal of Nutrition and Metabolism*, **2012**, Article ID: 851362. https://doi.org/10.1155/2012/851362

[34] Bai, J., Li, Y., Zhang, W., *et al.* (2021) Source of Gut Microbiota Determines Oat β-Glucan Degradation and Short Chain Fatty Acid-Producing Pathway. *Food Bioscience*, **41**, Article ID: 101010. https://doi.org/10.1016/j.fbio.2021.101010

[35] Chiozzi, V., Eliopoulos, C., Markou, G., *et al.* (2021) Biotechnological Addition of β-Glucans from Cereals, Mushrooms and Yeasts in Foods and Animal Feed. *Processes*, **9**, Article No. 1889. https://doi.org/10.3390/pr9111889

[36] Barsanti, L., Passarelli, V., Evangelista, V., *et al.* (2011) Chemistry, Physico-Chemistry and Applications Linked to Biological Activities of β-Glucans. *Natural Product Reports*, **28**, Article No. 457. https://doi.org/10.1039/c0np00018c

[37] Nakashima, A., Yamada, K., Iwata, O., *et al.* (2018) β-Glucan in Foods and Its Physiological Functions. *Journal of Nutritional Science and Vitaminology*, **64**, 8-17. https://doi.org/10.3177/jnsv.64.8

[38] Bulmer, G.S., de Andrade, P., Field, R.A. and van Munster, J.M. (2021) Recent Advances in Enzymatic Synthesis of *β*-Glucan and Cellulose. *Carbohydrate Research*, **508**, Article ID: 108411. https://doi.org/10.1016/j.carres.2021.108411

[39] Utama, G.L., Dio, C., Sulistiyo, J., *et al.* (2021) Evaluating Comparative *β*-Glucan Production Aptitude of *Saccharomyces cerevisiae*, *Aspergillus oryzae*, *Xanthomonas campestris*, and *Bacillus natto*. *Saudi Journal of Biological Sciences*, **28**, 6765-6773. https://doi.org/10.1016/j.sjbs.2021.07.051

[40] Mykhalevych, A., Polishchuk, G., Nassar, K., *et al.* (2022) *β*-Glucan as a Techno-Functional Ingredient in Dairy and Milk-Based Products—A Review. *Molecules*, **27**, Article No. 6313. https://doi.org/10.3390/molecules27196313

[41] Kaur, R., Sharma, M., Ji, D., *et al.* (2019) Structural Features, Modification, and Functionalities of Beta-Glucan. *Fibers*, **8**, Article No. 1. https://doi.org/10.3390/fib8010001

[42] Kim, H.J. and White, P.J. (2011) Optimizing the Molecular Weight of Oat *β*-Glucan for *in Vitro* Bile Acid Binding and Fermentation. *Journal of Agricultural and Food Chemistry*, **59**, 10322-10328. https://doi.org/10.1021/jf202226u

[43] Kim, H.J. and White, P.J. (2013) Impact of the Molecular Weight, Viscosity, and Solubility of *β*-Glucan on *in Vitro* Oat Starch Digestibility. *Journal of Agricultural and Food Chemistry*, **61**, 3270-3277. https://doi.org/10.1021/jf305348j

[44] Chen, C., Huang, X., Wang, H., *et al.* (2022) Effect of *β*-Glucan on Metabolic Diseases: A Review from the Gut Microbiota Perspective. *Current Opinion in Food Science*, **47**, Article ID: 100907. https://doi.org/10.1016/j.cofs.2022.100907

[45] Lazaridou, A., Biliaderis, C.G. and Izydorczyk, M.S. (2003) Molecular Size Effects on Rheological Properties of oat *β*-Glucans in Solution and Gels. *Food Hydrocolloids*, **17**, 693-712. https://doi.org/10.1016/S0268-005X(03)00036-5

[46] Petravi-Tominac, V., Zechner-Krpan, V., Berkovi, K., *et al.* (2011) Rheological Properties, Water-Holding and Oil-Binding Capacities of Particulate *β*-Glucans Isolated from Spent Brewer's Yeast by Three Different Procedures. *Food Technology and Biotechnology*, **49**, 56-64.

[47] Ramadhani, I., Larissa, D., Yuliani, Y., *et al.* (2020) Extraction, Characterization, and Biological Toxicity of *β*-Glucans from *Saccharomyces cerevisiae* Isolated from Ragi. *JMSB*, **2**, 35-43. https://doi.org/10.37604/jmsb.v2i2.62

[48] Thomas, S., Rezoagli, E., Abidin, I.Z., *et al.* (2022) *β*-Glucans from Yeast—Immunomodulators from Novel Waste Resources. *Applied Sciences*, **12**, Article No. 5208. https://doi.org/10.3390/app12105208

[49] Many, J.N. (2014) Analysis of Different Extraction Methods on the Yield and Recovery of *β*-Glucan from Baker's Yeast (*Saccharomyces cerevisiae*).

[50] Orlean, P. (2012) Architecture and Biosynthesis of the *Saccharomyces cerevisiae* Cell Wall. *Genetics*, **192**, 775-818. https://doi.org/10.1534/genetics.112.144485

[51] Aimanianda, V. (2017) Transglycosidases and Fungal Cell Wall *β*-(1,3)-Glucan Branching. *Molecular Biology*, **6**, Article ID: 1000194. https://doi.org/10.4172/2168-9547.1000194

[52] Boutros, J.A., Magee, A.S. and Cox, D. (2022) Comparison of Structural Differences between Yeast *β*-Glucan Sourced from Different Strains of *Saccharomyces cerevisiae* and Processed Using Proprietary Manufacturing Processes. *Food Chemistry*, **367**, Article ID: 130708. https://doi.org/10.1016/j.foodchem.2021.130708

[53] Du, L., Zhang, X., Wang, C. and Xiao, D. (2012) Preparation of Water Soluble Yeast Glucan by Four Kinds of Solubilizing Processes. *ENG*, **4**, 184-188. https://doi.org/10.4236/eng.2012.410B048

[54] Byun, E.-H., Kim, J.-H., Sung, N.-Y., *et al.* (2008) Effects of Gamma Irradiation on the Physical and Structural Properties of *β*-Glucan. *Radiation Physics and Chemistry*, **77**, 781-786. https://doi.org/10.1016/j.radphyschem.2007.12.008

[55] Ishimoto, Y., Ishibashi, K., Yamanaka, D., *et al.* (2017) Modulation of an Innate Immune Response by Soluble Yeast *β*-Glucan Prepared by a Heat Degradation Method. *International Journal of Biological Macromolecules*, **104**, 367-376. https://doi.org/10.1016/j.ijbiomac.2017.06.036

[56] Fu, W., Zhao, G. and Liu, J. (2022) Effect of Preparation Methods on Physiochemical and Functional Properties of Yeast *β*-Glucan. *LWT*, **160**, Article ID: 113284. https://doi.org/10.1016/j.lwt.2022.113284

[57] Huang, C., Miao, M., Jiang, B., *et al.* (2015) Polysaccharides Modification through Green Technology: Role of Ultrasonication towards Improving Physicochemical Properties of (1-3)(1-6)-*α*-d-glucans. *Food Hydrocolloids*, **50**, 166-173. https://doi.org/10.1016/j.foodhyd.2015.04.016

[58] Ma, X., Dong, L., He, Y. and Chen, S. (2022) Effects of Ultrasound-Assisted H_2O_2 on the Solubilization and Antioxidant Activity of Yeast *β*-Glucan. *Ultrasonics Sonochemistry*, **90**, Article ID: 106210. https://doi.org/10.1016/j.ultsonch.2022.106210

[59] Yang, W. and Huang, G. (2021) Extraction Methods and Activities of Natural Glucans. *Trends in Food Science & Technology*, **112**, 50-57. https://doi.org/10.1016/j.tifs.2021.03.025

[60] Chotigavin, N., Sriphochanart, W., Yaiyen, S. and Kudan, S. (2021) Increasing the Production of *β*-Glucan from *Saccharomyces carlsbergensis* RU01 by Using Tannic Acid. *Applied Biochemistry and Biotechnology*, **193**, 2591-2601. https://doi.org/10.1007/s12010-021-03553-5

[61] Zhu, F., Du, B. and Xu, B. (2016) A Critical Review on Production and Industrial Applications of Beta-Glucans. *Food Hydrocolloids*, **52**, 275-288. https://doi.org/10.1016/j.foodhyd.2015.07.003

[62] Mahmoud Amer, E., Saber, S.H., Abo Markeb, A., *et al.* (2021) Enhancement of *β*-Glucan Biological Activity Using a Modified Acid-Base Extraction Method from *Saccharomyces cerevisiae*. *Molecules*, **26**, Article No. 2113. https://doi.org/10.3390/molecules26082113

[63] Zohri, A.E.-N., Moubasher, H., Abdel-Hay, H. and Orban, M. (2019) Biotechnological *β*-Glucan Production from Returned Baker's Yeast and Yeast Remaining after Ethanol Fermentation. *Egyptian Sugar Journal*, **13**, 29-43. https://doi.org/10.21608/esugj.2019.219349

[64] Pengkumsri, N., Sivamaruthi, B.S., Sirilun, S., *et al.* (2016) Extraction of *β*-Glucan from *Saccharomyces cerevisiae*: Comparison of Different Extraction Methods and *in Vivo* Assessment of Immunomodulatory Effect in Mice. *Journal of Food Science and Technology*, **37**, 124-130. https://doi.org/10.1590/1678-457x.10716

[65] Liu, X., Wang, Q., Cui, S. and Liu, H. (2008) A New Isolation Method of *β*-d-Glucans from Spent Yeast *Saccharomyces cerevisiae*. *Food Hydrocolloids*, **22**, 239-247. https://doi.org/10.1016/j.foodhyd.2006.11.008

[66] Magnani, M., Calliari, C.M., de Macedo, F.C., *et al.* (2009) Optimized Methodology for Extraction of (1→3)(1→6)-*β*-d-Glucan from *Saccharomyces cerevisiae* and *in Vitro* Evaluation of the Cytotoxicity and Genotoxicity of the Corresponding Carboxymethyl Derivative. *Carbohydrate Polymers*, **78**, 658-665. https://doi.org/10.1016/j.carbpol.2009.05.023

[67] Varelas, V., Tataridis, P., Liouni, M. and Nerantzis, T. (2016) Application of Different Methods for the Extraction of Yeast *β*-Glucan. *e-Journal of Science & Tech-

nology (*e-JST*), **11**, 75-89.

[68] Borchani, C., Fonteyn, F., Jamin, G., *et al.* (2014) Enzymatic Process for the Fractionation of Baker's Yeast Cell Wall (*Saccharomyces cerevisiae*). *Food Chemistry*, **163**, 108-113. https://doi.org/10.1016/j.foodchem.2014.04.086

[69] Pham, K., Nhut, N. and Cuong, N. (2020) New Method for Preparing Purity β-D-Glucans (beta-Glucan) from Baker's Yeast (*Saccharomyces cerevisiae*). *Science and Technology Development Journal*, **23**, 673-678. https://doi.org/10.32508/stdj.v23i3.2051

[70] Tam, T.M. and Duy, N.Q. (2013) Optimization of β-Glucan Extraction from Waste Brewer's Yeast *Saccharomyces cerevisiae* Using Autolysis, Enzyme, Ultrasonic and Combined Enzyme-Ultrasonic Treatment. *American Journal of Research Communication*, **1**, 149-158.

[71] Avramia, I. and Amariei, S. (2022) A Simple and Efficient Mechanical Cell Disruption Method Using Glass Beads to Extract β-Glucans from Spent Brewer's Yeast. *Applied Sciences*, **12**, Article No. 648. https://doi.org/10.3390/app12020648

[72] Kofuji, K., Aoki, A., Tsubaki, K., *et al.* (2012) Antioxidant Activity of β-Glucan. *ISRN Pharmaceutics*, **2012**, Article ID: 125864. https://doi.org/10.5402/2012/125864

[73] Novak, M. and Vetvicka, V. (2008) β-Glucans, History, and the Present: Immunomodulatory Aspects and Mechanisms of Action. *Journal of Immunotoxicology*, **5**, 47-57. https://doi.org/10.1080/15476910802019045

[74] Sivieri, K., de Oliveira, S.M., Marquez, A.S., *et al.* (2022) Insights on β-Glucan as a Prebiotic Coadjuvant in the Treatment of Diabetes Mellitus: A Review. *Food Hydrocolloids for Health*, **2**, Article ID: 100056. https://doi.org/10.1016/j.fhfh.2022.100056

[75] Jaehrig, S.C., Rohn, S., Kroh, L.W., *et al.* (2008) Antioxidative Activity of (1→3), (1→6)-β-d-Glucan from *Saccharomyces cerevisiae* Grown on Different Media. *LWT—Food Science and Technology*, **41**, 868-877. https://doi.org/10.1016/j.lwt.2007.06.004

[76] Bozbulut, R. and Sanlier, N. (2019) Promising Effects of β-Glucans on Glyceamic Control in Diabetes. *Trends in Food Science & Technology*, **83**, 159-166. https://doi.org/10.1016/j.tifs.2018.11.018

[77] Chakraborty, S. and Devi Rajeswari, V. (2022) Biomedical Aspects of Beta-Glucan on Glucose Metabolism and Its Role on Primary Gene PIK3R1. *Journal of Functional Foods*, **99**, Article ID: 105296. https://doi.org/10.1016/j.jff.2022.105296

[78] Henrion, M., Francey, C., Lê, K.-A. and Lamothe, L. (2019) Cereal B-Glucans: The Impact of Processing and How It Affects Physiological Responses. *Nutrients*, **11**, Article No. 1729. https://doi.org/10.3390/nu11081729

[79] Korolenko, T.A., Bgatova, N.P., Ovsyukova, M.V., *et al.* (2020) Hypolipidemic Effects of β-Glucans, Mannans, and Fucoidans: Mechanism of Action and Their Prospects for Clinical Application. *Molecules*, **25**, Article No. 1819. https://doi.org/10.3390/molecules25081819

[80] MemnuneŞengül, S. (2022) Therapeutic and Functional Properties of Beta-Glucan, and Its Effects on Health. *JOR*, **6**, 29-41.

[81] Aljewicz, M., Nalepa, B. and Ciesielski, S. (2022) The Influence of Different Types of ß-Glucans on the Gut Microbiota of Rats Fed Milk Gels. *Journal of Functional Foods*, **89**, Article ID: 104930. https://doi.org/10.1016/j.jff.2021.104930

[82] Murphy, E.J., Rezoagli, E., Major, I., *et al.* (2020) β-Glucan Metabolic and Immunomodulatory Properties and Potential for Clinical Application. *Journal of Fungi*, **6**,

Article No. 356. https://doi.org/10.3390/jof6040356

[83] Bashir, K.M. and Choi, J.-S. (2017) Clinical and Physiological Perspectives of *β*-Glucans: The Past, Present, and Future. *International Journal of Molecular Sciences*, **18**, Article No. 1906. https://doi.org/10.3390/ijms18091906

[84] Galanakis, C.M., Aldawoud, T.M.S., Rizou, M., *et al*. (2020) Food Ingredients and Active Compounds against the Coronavirus Disease (COVID-19) Pandemic: A Comprehensive Review. *Foods*, **9**, Article No. 1701. https://doi.org/10.3390/foods9111701

[85] Caruso, M.A., Piermaria, J.A., Abraham, A.G. and Medrano, M. (2022) *β*-Glucans Obtained from Beer Spent Yeasts as Functional Food Grade Additive: Focus on Biological Activity. *Food Hydrocolloids*, **133**, Article ID: 107963. https://doi.org/10.1016/j.foodhyd.2022.107963

[86] Kaur, R. and Riar, C.S. (2020) Sensory, Rheological and Chemical Characteristics during Storage of Set Type Full Fat Yoghurt Fortified with Barley *β*-Glucan. *Journal of Food Science and Technology*, **57**, 41-51. https://doi.org/10.1007/s13197-019-04027-7

[87] Chirsanova, A.I., Boistean, A.V., Chiseliță, N. and Siminiuc, R. (2021) Impact of Yeast Sediment Beta-Glucans on the Quality Indices of Yoghurt. *Food Systems*, **4**, 12-18. https://doi.org/10.21323/2618-9771-2021-4-1-12-18

[88] Marinescu, G., Stoicescu, A. and Patrascu, L. (2011) The Preparation of Mayonnaise Containing Spent Brewer's Yeast *β*-Glucan as a Fat Replacer. *Romanian Biotechnological Letters*, **16**, 6017-6025.

[89] Vasquez Mejia, S.M., de Francisco, A., Manique Barreto, P.L., *et al*. (2018) Incorporation of *β*-Glucans in Meat Emulsions through an Optimal Mixture Modeling Systems. *Meat Science*, **143**, 210-218. https://doi.org/10.1016/j.meatsci.2018.05.007