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Beta-Glucans: Novel Sources, Green Extraction Techniques, and Health Benefits.

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Abstract

Beta glucans are a class of naturally occurring polysaccharides with many health benefits and industrial applications. This thesis aims to comprehensively review the current knowledge on β-glucans. The study focuses on their sources, extraction methods, health properties, and future trends in their application. The primary objective is to identify the most promising applications of β-glucans for companies, particularly as prebiotics. The objective is to explore sustainable extraction methods, including those utilising by-products from the food industry, such as brewer's yeast.

The researcher carefully gathers scientific articles and documents for this bibliographic thesis. The study evaluates the findings of several research studies in order to get new perspectives and interpretations. This methodological approach produces authoritative findings and pertinent recommendations thanks to a thorough and current literature synthesis. With this approach, the thesis gives a comprehensive review and new insights.

The introduction in Chapter 1 describes β-glucans at the molecular and chemical levels. The sources of beta glucans, such as barley, oats, mushrooms, yeast, and seaweed, as well as their functionalities and benefits, are discussed. The chapter's findings highlight the importance of source selection based on applications by demonstrating that β-glucans from various sources have diverse structures and bioactivities. Biological activity, solubility, and efficacy in health applications are determined by specific linkages β(1→6) and β(1→3).

Chapter 2 highlights the thesis' aim of promoting sustainable glucans production methods and beta glucans' practical applications. β-glucans are significant in science and industry; thus, this chapter prepares for study. The findings need further study to show the economic and environmental benefits of sustainable β-glucan production.

Traditional and modern methods for eliminating beta glucans are covered in Chapter 3. Mechanical, chemical, and newer enzymatic and ultrasonic extraction methods are used. This chapter compares environmentally friendly, cost-effective, and efficient methods. Following best practices are recommendations. Modern ultrasonic and enzymatic chemical extraction methods boost production and purity while reducing

environmental effect. This chapter optimises extraction parameters for efficiency and sustainability.

Beta glucans' specific health properties, such as their toxicity, cholesterol levels, and immunomodulatory effects, are examined in Chapter 4. The nutritional value and health benefits of β-glucans are covered. These findings suggest that β-glucans lower cholesterol and enhance immunity, making them useful in functional foods and supplements. Modifying gut flora shows beta glucans' health benefits in this chapter.

Chapter 5 discusses current and future trends in β-glucans production and application. Sustainable food industry products are investigated, with a focus on sustainable food production methods. Emerging applications, such as prebiotics, are also mentioned. In order to improve beta glucan production, this chapter includes covers green and innovative extraction methods. Sustainable β-glucans production methods are beneficial to the environment and economy. Beta glucans' distinctive properties and potential Biomedical and Cosmetic applications are also covered in this chapter.

Key conclusions from the thesis and their implications for research and industry are summarised in Chapter 6. Beta glucans and their applications are highlighted, and future research recommendations are made. β-glucans are a versatile and important resource with potential for health and industry applications. Sustainable source extraction methods require further study and modification. The conclusions show that beta glucans' full potential requires cross-disciplinary cooperation.

Chapter 7 case study by Gabrielle et al. (2022) examines BSY (brewer's wasted yeast) as a source of β-glucan. The presence of β-glucan, a polysaccharide with vital biochemical and physiological properties, distinguishes BSY, a beer by-product. Focusing on yield, purity, and functional properties, the study analyses β-glucan extraction methods from BSY. Due to its β-(1,3) and β-(1,6) glycosidic connections, BSY-produced β-glucan has antioxidant, hypocholesterolemic, and immunomodulatory properties. This study emphasises the environmental and industry benefits of using BSY for β-glucan extraction, promoting sustainable brewing methods. Research suggests BSY β-glucan could aid the food industry by converting brewery waste into commercial products.

According to this thesis, β-glucans are flexible and promising in functional foods and supplements. In order to educate industry stakeholders, this study examines sustainable extraction methods and applications. Recent research and future sources emphasise the importance of β-glucans for human health and sustainable industrial operations. This thesis suggests studying beta glucans' extraction methods, new applications, and long-term health advantages. Besides environmental and industrial benefits, sustainable methods reduce waste and generate new opportunities.

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Table of Contents

Chapter 1: Introduction

1.1. Definition of Beta Glucan as Molecular and Chemical Characteristics

Du et al. (2019) define beta glucans as glucose polymers containing glycosidic linkages. Cell wall construction and metabolism rely on β-glucans, which serve as structural components in fungi, plants, and certain bacteria. In plants, particularly oats and barley, β-glucans are vital for cell wall integrity, while in fungi (e.g., yeast and mushrooms), they play a critical role in both cell wall formation. In recent decades, scientists have investigated β-glucan sources and agro-food waste utilisation (Bobade et al., 2022). Beta-glucan, a non-starch polysaccharide, has over 25,000 linear glucose chains linked by β-(1→3), β-(1→4), and/or β-(1→6) D-glycosidic linkages (Liu et al., 2021). Water-soluble and non-water-soluble glucans are the two main types. Salecan and curdlan are examples of water-soluble glucans. The solubility of beta-glucan depends on its chemical composition, molecular mass, crude manufacture, and structure (Mejía et al., 2020).

Beta-glucans are predominantly found in the cell walls of fungi (such as yeast and mushrooms) and plants (such as barley and oats) (Fang et al., 2021). Fungi, plants, algae, lichens, and microorganisms are the primary living organisms that produce beta-glucans (Kaur et al., 2019). The concentration of beta-glucans varies across different organisms, with the highest levels found in cereals such as barley and oats and lower levels in wheat and rice. Additionally, beta-glucan is found in agricultural by-products, such as the bran of cereal grains, which makes extraction and isolation from these sources both economically viable and environmentally sustainable (Nakashima et al., 2018).

Beta glucans are linear or branched polysaccharides made of glucose units connected by β-glycosidic bonds. Golisch et al. (2021) believed that the specific arrangement of these bonds, especially β(1→3), β(1→4), and β(1→6) determines beta glucans' shape and functional properties. The helical structure of β(1→3)-linked glucans improves their water solubility and interaction with immunological receptors like dectin-1, which are essential for immune regulation and defensive mechanisms (Sofi et al., 2017).

Fungal beta glucans exhibit structural variation due to branching patterns, such as β(1→6) connections (Borchani et al., 2016). These branches confound receptor interactions and cellular reactions. Understanding these structural features helps beta glucans function in varied physiological circumstances (Goudar et al., 2020).

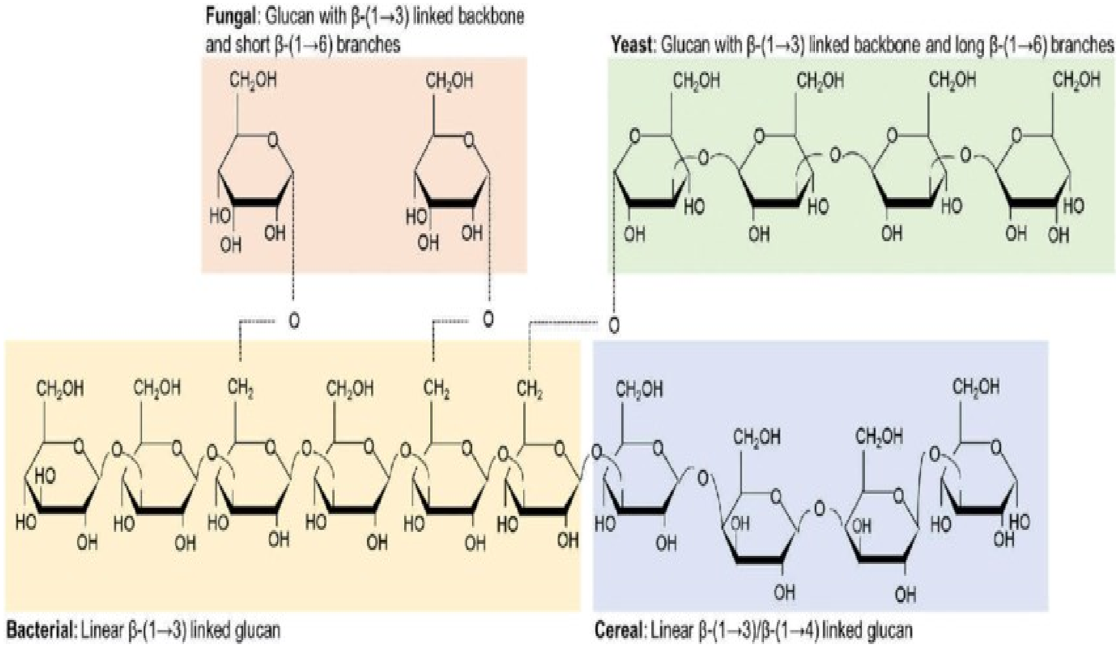

Figure 1: Glucans and their Chemical Structures

(Source: Borchani et al., 2016)

Golisch et al. (2021) claimed beta glucan structure determines chemical properties. gelsidic linkages impact polysaccharide chain solubility, viscosity, and bioactivity. Bobade et al. (2022) found that the helical structure of β(1→3) glucans improves their immunomodulatory and water-soluble properties. Oats and barley's glucans limit fibre content via affecting viscosity and texture.

Fungi and yeast glucans with β(1→6) linkages exhibit increased structure complexity. To boost immunomodulation and antioxidant properties, these branches modify immune cell and receptor interactions (Liu et al., 2021). Beta glucans can be stabilized and disintegrated utilising chemical or enzymatic methods for chemical and medicinal applications (Aboushanab et al., 2019).

Yuan et al. (2019) stated that the prebiotic activities of beta-glucan maintain serum cholesterol, blood sugar levels, cardiovascular disease, hypertension, cancer, and immune-enhancing properties. Many of beta-glucan's physiological functions depend on its high molecular weight-dependent viscosity. The US Food and Drug Administration recommends 3 grams of beta-glucan daily with a low-cholesterol diet to minimize cardiovascular disease risk (Bai et al., 2021).

Beta-glucans regulate metabolism, immunity, and health. PRR-induced signalling promotes cytokine synthesis and phagocytosis. Immunomodulation is needed for infection resistance and surveillance. Mejía et al. (2020) found that beta glucans enhance immunological health and cholesterol metabolism. Reducing intestinal cholesterol absorption may improve cardiovascular health. Beta glucans restored intestinal flora.

Wang et al. (2017) said that Beta glucans' market exposure and commercial viability matter economically. Beta-glucans' biological activity and applications have raised their global market share. Healthy dietary fibres and compounds are beta glucans. Due to their cholesterol-lowering and prebiotic properties, beta glucan-containing oats, cereals, and baked goods may appeal to natural cardiovascular and digestive health enthusiasts (Fang et al., 2021).

Medication and supplements benefit from beta glucans' immunomodulatory properties (Aboushanab et al., 2019). Natural pharmaceutical alternatives and preventative health care are growing this sector.

Beta glucans' moisturising and anti-aging properties are utilized in cosmetics (Nakashima et al., 2018). This example shows beta glucans' adaptability and appeal across consumer industries, boosting their global economic importance.

New health advantages, extraction methods, and product formulations are making beta glucans profitable (Bobade et al., 2022). Customer demand for natural, functional ingredients drives beta glucans' international health and wellness industry growth and innovation despite manufacturing costs and regulatory constraints (Sofi et al., 2017).

1.2. Different Sources & Chemical Properties of Beta-Glucans (Beneficially & Functionality)

1.2.1. Linkages β 1,6 and β 1,3

1.2.1.1 β(1→6) Linkage

Beta glucans have branched structures with C1 and C6 glucose units connected by -glycosidic linkages (Liu et al., 2021). Polysaccharide chain branching affects solubility and receptor interactions.

Structural Linkage: β(1→3) in comparison to β(1→6), adds branching sites to the beta glucans' backbone, boosting structural linkage (Bai et al., 2021). This branching pattern's three-dimensional conformation affects water-containing liquids' spatial arrangement and molecular flexibility.

Biological Functions: Beta glucans with β(1→6) linkages affect immunity. These polysaccharides engage immune cell receptors like dectin-1 to initiate signalling pathways that increase immunological surveillance and protection. The branching structure of β(1→6) glucans may exert greater immunostimulatory effects than linear glucans due to their interaction with many immunological receptors (Borchani et al., 2016).

Studies show that yeast and fungal glucans promote phagocytosis and cytokine production (Du et al., 2019). Its immunomodulatory activities boost immunity and infection resistance in diverse physiological situations. According to Nakashima et al. (2018), β(1→6) linkages can alter the molecule's interaction with water molecules, unlike the normal water-soluble helical structures of β(1→3) glucans. This shift in solubility properties affects the viscosity and rheology of glucans in solution, affecting their applications in food, medicine, and medicine.

1.2.1.2 β(1→3) Linkage

Beta glucans are linear glucose chains with C 1 and C 3 glycosidic linkages (Kaur et al., 2019). Linear structure affects receptor interactions, biological processes, and molecular conformation (Sofi et al., 2017). (Glucans) linkage gives Beta glucans helical structures that improve water solubility and stability. Repeating β(1→3) glycosidic linkages create triple helices, stabilising and enhancing water solubility by wrapping three polysaccharide chains.

Bioactivity: Beta glucans with certain linkages have immunomodulatory properties and can activate innate immunity. Polysaccharides activate immune cell dectin-1 and complement receptors, enhancing cytokine synthesis, phagocytosis, and immune cell activation. Cascades signal. Immune receptors recognize β(1→3) glucans' helical structure, enhancing immunostimulatory effects compared to other linkages (Bai et al., 2021). Wound healing, germ defense, and immunological monitoring require immune system modulation.

The helical structure of linkages β(1→3) makes beta glucans water-soluble and stable. These glucans are functional as food additives, pharmaceutical excipients, and biological components due to their capacity to form gels and viscoelastic networks (Bikmurzin et al., 2022). The solubility properties of β(1→3) glucans affect their applications in dietary supplements, where they enhance digestion and immunity.

1.2.2. Barley and Oats

Beta glucans are polysaccharides with several health benefits and functional properties, according to Sourki et al. (2017). Beta glucans, complex polysaccharides from barley and oats, consist of glucose units connected by β-glycosidic linkages. Beta glucans in barley have a backbone structure with (1→3) linkages and (1→4), while oats have a higher amount of (1→3) linkages interspersed with (1→4). Their solubility, viscosity, and functional properties vary due to structure.

Most beta glucans are in barley's endosperm and aleurone. The physiological structure of barley grain impacts texture and function. Molecular weight affects barley beta glucans' physiological effects (Goudar et al., 2020). Studies show that higher-molecular-weight barley beta glucans decrease cholesterol more.

Beta glucans are in oat bran and endosperm (Mäkelä et al., 2021) High water solubility creates viscous solutions, which improve the functional properties. Viscosity slows digestion and improves satiety in oat beta glucans depending on molecular weight and polymerisation.

1.2.2.1 Benefits and Functionalities

Soluble dietary fibres including barley and oat beta glucans improve digestion and health (Bai et al., 2021). As soluble fibres, they form intestinal gels, slowing stomach emptying and glucose absorption. This helps regulate blood sugar, making barley and oats suitable for diabetic and obese diets.

Beta glucans' viscousness promotes fullness and satiety, regulating weight, according to Karimi et al. (2017). Beta-glucan-rich barley and oats help lose weight. Barley and oat beta glucans have been extensively studied for their potential health benefits, including the reduction of LDL cholesterol. Beta glucans impede intestinal absorption by binding to cholesterol-breaking bile acids (Sofi et al., 2017). Excreting cholesterol lowers LDL cholesterol and cardiovascular disease risk.

Many clinical trials and meta-analyses (Nakashima et al., 2018; Kaur et al. 2019; and Goudar et al. (2020) demonstrate that beta glucans from barley and oats lower cholesterol. Oat beta glucan has been shown to significantly reduce LDL cholesterol levels, and products containing sufficient amounts can therefore reduce the risk of heart disease, according to the FDA (Nakashima et al., 2018). A meta-analysis conducted by Kaur et al. (2019) confirmed the cholesterol-lowering properties of beta glucans, particularly in reducing total and LDL cholesterol. Another study by Goudar et al. (2020) showed that high doses of beta glucans significantly decreased LDL cholesterol levels across various populations. Additionally, research by Varelas et al. (2016) demonstrated improved lipid profiles with long-term beta glucan consumption, highlighting its cardiovascular benefits.

The cholesterol-lowering properties of barley and oat beta glucans boost cardiovascular health. Coronary heart disease and other cardiovascular disorders are linked to high LDL cholesterol (Fang et al., 2021). Barley and oat beta glucans lower LDL cholesterol, increasing heart health and longevity.

Beta glucans may reduce inflammation and enhance endothelial function. Secondary effects prevent and improve cardiovascular health.

Barley and oat beta glucans exhibit immunomodulatory properties in addition to cholesterol metabolism. They help macrophages and dendritic cells fight infections and monitor the immune system.

Beta glucans activate immune cells and enhance cytokine production via PRRs such dectin-1 (Mejía et al., 2020). This immunomodulatory activity assists persons with compromised immune systems or who want to boost immunity naturally.

Other Uses: Beta glucans from barley and oats thicken and stabilize meals (Liu et al., 2021). They add viscosity and mouthfeel without altering taste, making them helpful in soups, sauces, dairy products, and baked goods.

Their ability to form gels and emulsions enhances food processing and cooking (Bobade et al., 2022). Pharmaceuticals and cosmetics use beta glucans for their bioactive dietary benefits, such as wound healing, anti-inflammatory effects, and skin moisturising properties.

1.2.3. Mushrooms, Yeast, and Seaweed

1.2.3.1 Mushrooms

Chiozzi et al. (2021) noticed beta glucans in barley, oats, mushrooms, yeast, and seaweed have different chemical compositions and health benefits. Shiitake (*Lentinula edodes*), reishi (*Ganoderma lucidum*), and maitake (*Grifola frondosa*) mushrooms contain beta glucan. Beta glucans in mushrooms, β(1→3)- and β(1→6), regulate biological activity through branching patterns (Bikmurzin et al., 2022). Structure and protection are provided by polysaccharides in mushroom cell walls.

Health benefits of beta glucans in mushrooms include their immune-modulating properties, as they interact with macrophages and dendritic cells through dectin-1 receptors (Borchani et al., 2016). This interaction enhances innate immune functions like phagocytosis, cytokine secretion, and NK cell activation. *In vitro* studies have shown that beta glucans activate immune cells and stimulate cytokine production in cell cultures (Liu et al., 2021). Furthermore, *in vivo* studies in animal models demonstrate enhanced immune response, with beta glucans increasing the activity of immune cells and improving infection resistance in mice (Kaur et al., 2019).

Mushroom beta glucans also exhibit strong antioxidant properties, which reduce oxidative stress and may lower the risks of obesity and cancer by preventing cellular oxidative damage. *In vitro* studies have revealed that mushroom beta glucans can scavenge free radicals and reduce oxidative stress in human fibroblast cell cultures (Mejía et al., 2020). *In vivo trials*, including a double-blind, placebo-controlled study on 45 human participants (aged 40-65), confirmed the antioxidant effects, with reductions in oxidative stress biomarkers after 8 weeks of beta glucan supplementation (Nakashima et al., 2018).

1.2.3.2 Yeast

Another major source of beta glucans is *Saccharomyces cerevisiae* yeast. Avramia & Amariei (2021) found that yeast beta glucans are mainly made up of β(1→3) and β(1→6) linkages, with changes in structure and content based on strain and growth conditions. In yeast's cell wall structure, these polysaccharides let it survive in many environments.

Benefits: Beta glucans from yeast have immunomodulatory properties similar to mushroom beta glucans (Bobade et al., 2022). They increase phagocytosis and cytokine production by interacting with immunological receptors on macrophages and other immune cells. This immune activity helps people fight infections and other diseases.

Antioxidant actions help yeast beta glucans fight oxidative stress and inflammation (Liu et al., 2021). Yeast beta glucans may improve cellular health and longevity by lowering free radical damage and increasing antioxidant enzyme activity.

Research suggests that yeast beta glucans can enhance immune function and vaccine responses (Mejía et al., 2020). They are potential candidates for therapeutic applications to increase immune defences and infection resilience due to their ability to control immunological responses without creating excessive inflammation.

1.2.3.3 Seaweed

Seaweed contains polysaccharides and beta glucans (Melo et al., 2020). Ocean-specific fucoidan and laminarin beta glucans are biologically active and structured (Raimundo et al., 2017). Immune system modulation and antioxidant protection are seaweed beta glucan benefits. Brown seaweeds like wakame and kelp include laminarin, a $\beta(1\rightarrow3)$-linked glucan that boosts cytokine synthesis and immune cell activation. Immunostimulation boosts pathogen defence and immunology (Rehman et al., 2024).

Seaweed Beta glucans have antioxidant properties that reduce free radicals and oxidation. Antioxidants lower cardiovascular and neurological disorders. Seaweed beta glucans' anti-inflammatory properties may boost immunity and reduce health risks (Aboushanab et al., 2019). Due to their biological properties, seaweed beta glucans are used in health-promoting meals, supplements, and cosmetics.

Chapter 2: Aim of the Thesis

The aim of this thesis is to collect and discuss the literature on beta glucans. The goal is to comprehensively explore the potential and applications of beta glucans, focusing on their characteristics, extraction methods, health properties, and research trends.

Objectives of the study are:

- To describe beta glucans and their molecular and chemical properties.
- To discuss traditional and modern extraction techniques of beta glucans from various sources, highlighting their efficiency and sustainability.
- To report the health benefits associated with beta glucans, including their impact on cholesterol levels, immunomodulation, and overall nutrient quality.
- To discuss current and emerging applications of beta glucans, focusing on their potential as prebiotics and the development of sustainable production methods.

Chapter 3. Extraction Methods

3.1. Traditional Techniques

3.1.1. Chemical Methods

According to Karimi et al. (2019) chemical methods break cell walls and release polysaccharides to extract beta glucans. Source material (plant or fungal), beta glucans' desired purity, and bioactivity are considered when choosing solvent and extraction conditions (Minerviniet al., 2022). In industrial settings and research, this overview focuses on key chemical extraction methods.

3.1.1.1 Alkaline Extraction

NaOH or KOH break plant or fungal cell walls. According to Mejía et al. (2020) beta glucans are released into the extraction solution when alkaline treatment breaks down cellulose and hemicellulose. Alkaline environments help beta glucans from sources like barley, oats, and fungi. Extraction, neutralisation, and precipitation are needed to purify beta glucans from acidic solution (Li, 2018).

When separating beta glucans from natural sources, alkaline glucan extraction methods offer the following benefits:

- Productivity and Efficiency: Alkaline solutions like NaOH or KOH successfully release beta glucans into the extraction solution. Beta glucans are easily produced from biomass using this approach (Varelas et al., 2016).
- Alkaline extraction alters temperature and pH to preferentially remove beta glucans. Downstream purification is easier when polysaccharides dissolve with lignin and cellulose.
- Alkaline extraction provides enough beta glucans for industrial applications. Process optimisation improves polysaccharide quality and quantity.
- This extraction approach is less expensive than enzymatic or organic solvent methods since alkaline reagents are readily available (Sourki et al., 2017).

Despite its benefits, alkaline extraction has certain drawbacks:

- Beta glucans may leave chemical residues impacting bioactivity and purity after alkaline treatment (Mahmoud et al., 2021). Beta glucans' properties may be impacted by residual alkali, requiring additional purification.

- Polysaccharides, especially beta glucans, change in molecular structure and functional properties when break by extremely acidic conditions. Manage extraction parameters to prevent deterioration.
- Controlling alkaline waste decreases extraction's environmental impact.

Examples: Beta glucans are extracted from plant and fungal cell walls by NaOH extraction. NaOH hydrolyzes hemicellulose and lignin ester linkages, destroying network structures. The extraction medium has soluble beta glucans. After extraction, Beta glucans must be neutralised with HCl or CHCOOH to precipitate (Yuan et al., 2019).

Kaur et al. (2019) found that potassium hydroxide (KOH), which is derived from sources like barley and oats, is used in the alkaline extraction of beta glucans. When KOH break cell wall cellulose and hemicellulose, beta glucans are liberated into the extraction solution. Beta glucan solubility and recovery are enhanced by pH and temperature. Beta glucans are filtered and precipitated following extraction to remove alkali and other impurities (Dimopoulos et al., 2020).

3.1.1.2 Acid Hydrolysis

Singla et al. (2024) stated that using HCl or sulfuric acid, acidic hydrolysis removes glycosidic linkages from plant or fungal cell walls. Following acidic hydrolysis, the structural components such as cellulose and pectin are broken down, allowing beta glucans to be released into the extraction medium. Acid hydrolysis releases polysaccharides and leaves insoluble residues from beta glucans in oats and barley (Goudar et al., 2020). Regulate pH and reaction conditions to preserve beta glucans during extraction.

Advantages:

- Acid hydrolysis eliminates plant/fungal beta glucans.
- Acid releases beta glucans but leaves insoluble glycosidic linkages. This is extraction selection. Selective polysaccharide isolation is conceivable.
- High beta glucans yields can be obtained from biomass sources like oats and barley because acid hydrolysis efficiently breaks down complex polysaccharides found in cell walls (Melo et al., 2020).

- Beta glucans' structural integrity can be protected by regulating pH, temperature, and reaction time during hydrolysis.
- To improve product recovery and purification, acid hydrolysis produces soluble beta glucan fractions for processing and filtration downstream (Alzorqi et al., 2017).

Limitations:

- Beta glucans that are acidic must be neutralized.
- Strong acids can structurally alter beta glucans.
- Environmental Concerns: Acidic waste after extraction must be controlled for safety and environmental protection (Din et al., 2018).

Examples:

According to Zhu et al. (2016) acid hydrolysis of beta glucans in cereals like barley and oats by HCl. Beta glucans are released into the extraction solution as soluble polysaccharides after acid hydrolysis of glycosidic linkages in cell wall components. Control pH and reaction time to preserve the structural integrity of beta glucans. Reduce beta glucans via neutralising and filtering hydrolysis.

Sulfuric acid breaks down biomass beta glucans. Beta glucans are released when cell wall polysaccharides degrade in extremely acidic circumstances (Venkatachalam et al., 2021). Sulfuric acid hydrolysis removes high-molecular-weight beta glucans in yeast and mushrooms Hydrolysis, followed by precipitation and refining, generates very pure polysaccharide fractions from beta glucans. However, it is important to consider whether the glucans extracted through hydrolysis are less polymerized (i.e., consist of shorter chains) compared to those obtained via alkali extraction.

3.1.1.3 Enzymatic Hydrolysis

Enzymatic hydrolysis breaks down complex polysaccharides in plant and fungal cell walls. Before enzyme treatment, chemical pre-treatments weaken cell walls and promote enzyme accessibility (Bulmer et al., 2021). This method releases beta glucans slowly and selectively with minimal degradation. Because of its specificity, enzymatic hydrolysis can be used to extract beta glucans from mushrooms and yeast without causing structural damage.

Advantages:

- Enzymatic hydrolysis extracts natural beta glucans.
- By selectively hydrolysing glycosidic linkages in cell walls, cellulases and hemicellulases maintain the bioactivity and integrity of beta glucans under moderate circumstances (Lante & Canazza, 2023).
- Enzymatic synthesis of beta glucan fractions leads to lower cellular contamination, which reduces the need for extensive purification processes.
- Enzymatic hydrolysis protects the bioactivity of beta glucans without structural modifications (Tian et al., 2019).
- Biodegradable catalysts for enzymatic reactions benefit the environment.

Limitations:

Despite its benefits, enzymatic hydrolysis has some limitations:

- Enzymes typically cost more than chemicals. Cost-effective extraction relies on careful adjustment of enzyme dosage and reaction conditions. However, it is important to note that cheaper enzymes are often not pure and may exhibit additional activities, such as proteolytic effects (De Iseppi et al., 2019).
- Process Optimisation: pH, temperature, substrate concentration, and specificity affect enzyme activity (Mykhalevych et al., 2022). Tune these variables for extraction yield and efficiency.
- Reaction Time: Enzymatic hydrolysis may take longer than chemical methods, reducing industrial process scalability and throughput.
- Enzyme stability and lifetime guarantee are needed to preserve hydrolytic activity and reduce extraction variability.

Examples:

The hydrolysis of β(1→4) linkages in plant cell walls is facilitated by specific enzymes known as cellulases, which include various types that may also play a role in the extraction of beta glucans (Murphy et al., 2023). After enzymatic treatment, alkali or steam explosion can improve enzyme accessibility. Cellulase breaks down cellulose into glucose and smaller oligosaccharides, releasing beta glucans as soluble polysaccharides. Bioactive and structural beta glucans are carefully removed utilising specialized enzymatic hydrolysis.

The hemicellulase enzyme targets β(1→4) and β(1→3) linkages in plant cell wall hemicellulose (Mykhalevych et al., 2022). Beta glucans enter the extraction solution as soluble polysaccharides as enzymes hydrolyze hemicellulose polymers. Full cell wall polysaccharide hydrolysis requires mesocellulases and cellulases. Enzymatic hydrolysis uses natural catalysts that are efficient in mild conditions without significantly jeopardising the structural integrity of beta glucans, making it both ecologically and biocompatible (Li, 2018).

3.1.1.4 Organic Solvent Extraction

According to Mejía et al. (2020) the solubility of beta glucans in non-polar solvents including ethanol, methanol, and chloroform is used in organic solvent extraction of these compounds. This method extracts lower-molecular-weight beta glucans from fungi with chemically degraded cell walls. Organic solvents efficiently separate and purify beta glucans without cell damage. Selecting the right solvent and extraction conditions preserves bioactive beta glucans and prevents contamination (Minerviniet al., 2022).

Advantages:

- Organic solvent extraction isolates beta glucans well. Beta glucans can be dissolved in nonpolar organic solvents including ethanol, methanol, and chloroform, especially those from fungi or with lower molecular weight.
- Selective Extraction: Organic solvents dissolve beta glucans without harming other cells, simplifying purification and processing (Mykhalevych et al., 2022).
- Efficiency: Because solvent extraction quickly removes beta glucans from biomass, it is ideal for industrial use.
- Beta glucans from solvent extraction can be dried, refined, and used.

Limitations:

- Organic solvents in extracted beta glucans may impact product purity and safety, requiring rigorous purification.
- The environmental impact of organic solvent waste is difficult to eliminate.
- Industrial organic solvents must be safe because they can injure workers.

Examples:

Kaur et al. (2019) found that ethanol extraction uses a non-polar organic solvent to separate beta glucans from fungal sources without harming the cell wall chemically. Beta glucans are dissolved in ethanol to precipitate polysaccharides without hurting other cells. For beta glucan solubility and yield, optimize solvent concentration and temperature during extraction (Varelas et al., 2016).

Like ethanol extraction, methanol extraction isolates beta glucans from fungal biomass. Methanol's solvent properties break down beta glucans, making polysaccharide extraction easier with less cellular contact (Sourki et al., 2017). Methanol is poisonous and flammable, so handle it carefully.

Table 1: Comparison of Chemical Extraction Methods

Chemical Extraction Method	Advantages	Limitations	Examples of Specific Processes
Alkaline Extraction	- High yield of beta glucans - Scalable for industrial applications (Mahmoud et al., 2021). - Selective extraction with proper pH control	- Residual alkali may affect purity - Potential degradation of beta glucans - Environmental impact of alkali waste	- Sodium hydroxide (NaOH) extraction - Potassium hydroxide (KOH) extraction - Ammonium hydroxide (NH_4OH) extraction
Acid Hydrolysis	- Selective hydrolysis of glycosidic linkages - Efficient extraction from plant and fungal sources - Controlled reaction conditions	- Residual acids require neutralisation - Risk of beta glucan degradation - Environmental concerns with acidic waste (Dimopoulos et al., 2020).	- Hydrochloric acid (HCl) hydrolysis - Sulfuric acid (H_2SO_4) hydrolysis - Nitric acid (HNO_3) hydrolysis
Enzymatic Hydrolysis	- Specificity for beta glucan linkages - Mild reaction conditions preserve bioactivity - Biocompatible and environmentally friendly (Yuan et al., 2019).	- High cost of enzymes - Longer reaction times - Enzyme stability and specificity challenges	- Cellulase enzyme treatment - Hemicellulase enzyme treatment - β-glucosidase enzyme treatment
Organic Solvent Extraction	- Efficient extraction of low	- Solvent residues impact purity -	- Ethanol extraction - Methanol

	molecular weight beta glucans - Compatible with downstream processing - Minimal interference from other cellular components	Safety hazards (flammability, toxicity) - Environmental impact of solvent waste (Alzorqi et al., 2017).	extraction - Chloroform extraction

3.1.2 Molecular Methods

Traditional molecular extraction techniques for beta glucan involve harsh chemical treatments, high temperatures, and complex processing (Minerviniet al., 2022). These methods have been significant in extracting beta glucan from natural sources such as cereal grains (oats, barley), yeast, and mushrooms, allowing us to understand its properties and applications in many areas.

3.1.2.1 Hot Water Extraction

According to Karimi et al. (2019) one of the oldest and most used methods is the hot water extraction of beta glucan from cereal grains, particularly oats and barley. Use beta-glucan's solubility in hot water by heating the source material to 60–100°C. Filtration or centrifugation removes insoluble components from dissolving beta-glucan and other components in hot water.

The simple hot water extraction process requires only heat and time to maximise beta glucan and prevent degradation (Li, 2018). Beta glucan extracts are used in food and nutraceutical applications in varying degrees of purity. Additional purification steps may be required to achieve pure beta glucan process because hot water extraction eliminates proteins and lipids. Since it is included in functional foods and nutritional supplements that lower cholesterol and strengthen the immune system, the production of oat beta glucan applications using hot water extraction is advantageous. According to Mejía et al. (2020) despite working, hot water extraction is less eco-friendly than current methods due to its energy and waste consumption.

3.1.2.2 Acid and Alkaline Extraction

In acid and alkaline extraction methods, beta glucan dissolves (Varelas et al., 2016). Acid extraction removes cell wall beta glucan. By heating the acid solution and input material, the extraction process starts. To recover beta glucan, neutralise and filter the mixture. Sodium or potassium hydroxide solutions are used for alkaline extraction. Acidic liquids damage cell walls by destroying beta glucan and hydrolysing ester linkages. Filtration and neutralisation recover beta-glucan.

Although other useful components may be lost, acid and alkaline extraction methods extract beta glucan. These methods optimise beta-glucan synthesis and purity by controlling extraction duration, temperature, and pH (Varelas et al., 2016). Acidic extraction waste may harm the environment.

3.1.2.3 Enzymatic Extraction

Enzymatic extraction isolates natural beta glucansources (Varelas et al., 2016). Enzymes that target cell wall matrix connections govern beta-glucan extraction. To enhance enzyme surface area, the process begins with ground or milled raw material. Mixing the material with a pH- and temperature-optimal enzyme solution boosts enzyme activity. The enzymatic hydrolysis process releases beta-glucan from cellulosic and hemicellulosic materials.

Enzymatic extraction crushes chemical and physical methods. Heat degradation is reduced and beta-glucan bioactivity is maintained in milder conditions (Sourki et al., 2017). Biodegradable, renewable resources are needed for enzyme extraction. Enzymatic extraction may take longer and cost more to process than other methods. According to Mejía et al. (2020) enzymatic extraction extracting beta glucans from cells that breaks down cell walls with enzymes. This method is popular because it is effective, long-lasting, and protects beta glucans' functional characteristics. Enzymatic extraction is optimal for processing plant, fungus, and yeast since mechanical or chemical methods eliminate bioactive components (Varelas et al., 2016).

<u>Cellulase Enzymes:</u>

Cellulase enzymes degrade cellulose, a component of plant cell walls. The hydrolysis of β-glucan linkages breaks cellulose's rigid structure, releasing beta glucans (Borchani et al., 2016). Cellulase enzymes are necessary for the metabolic extraction of beta glucans from barley and oats.

β-Glucanase Enzymes:

β-Glucanases break down β(1→3) and β(1→4) linkages in β-glucans, a carbohydrate found in mushrooms and yeast (Mykhalevych et al., 2022). These enzymes hydrolyze fungal cell wall polysaccharides to enable the extraction of soluble beta glucans.

Hemicellulase Enzymes:

Plant cell wall hemicellulose is targeted by hemicellulases. The beta glucans attached to the side chains of hemicellulose polymers enhance hydrolysis (Murphy et al., 2023). In order to release beta glucans from agricultural waste, hemicellulose is broken down by enzymes.

Enzymatic extraction methods optimise pH, temperature, and incubation. Gentle processing preserves beta glucans' structural integrity and bioactivity, unlike mechanical or chemical extraction methods. Since enzymes reduce waste, the extraction process is eco-friendlier.

Process of Enzymatic Extraction Methods:

Cellulases, hemicellulases, and glucanases break down biomass cell walls during extraction. During the breakdown process of cell wall polysaccharides, these enzymes release beta glucans (Łubek-Nguyen et al., 2022). Enzymatic extractions often require the following:

- Prepared biomass makes enzymes accessible. Particle size is altered during milling.
- Biomass is treated with enzymes prior to the process. Incubating at the proper temperature, pH, and time increases enzyme activity (Łubek-Nguyen et al., 2022).
- Beta glucans are produced by enzymes breaking down cell wall polysaccharides. Biomass and enzymes determine this process's duration (Goudar et al., 2020).
- Solid residue hydrolysate contains beta glucans. Filtration, centrifugation, and precipitation complete the beta glucans process for purity.

Efficiency and Sustainability in Enzymatic Techniques

Enzymatic extraction is mild and selective in comparison to other methods. Advantages include:

- High Specificity: Enzymes release beta glucans efficiently without byproducts by targeting cell wall polysaccharide linkages.
- Mild Conditions: The process conserves energy while maintaining the bioactivity of beta glucans by employing ambient temperatures and neutral pH (Lante & Canazza, 2023).
- Sustainability: Enzymatic extraction is an environmentally friendly method. It cuts downstream filtering, harsh chemicals, and trash. Make sustainable biodegradable enzymes.
- Scalability: In business, the method works. Enzymatic processes are straightforward to monitor and optimise for industrial output.
- However, enzymatic extraction has downsides. The process may require expensive enzymes and biomass optimisation. Due to several factors, extraction conditions alter enzyme stability and activity (Bikmurzin et al., 2022).

<u>Case Studies:</u>

Case Study 1: Enzymatic Barley Beta Glucan Extraction

The extraction of barley beta glucans used cellulase and β-glucanase enzymes. Milling barley grains reduced particle size before treatment with enzymes at controlled temperature and pH (Venkatachalam et al., 2021). Beta glucans were created when cell wall components were destroyed by enzymes. Beta glucans were purified and characterised while maintaining their bioactivity and purity. This process proved that cereal grains may be removed using an enzymatic method to create high-quality beta glucans.

Enzymatic Yeast Extraction: Another work used lytic enzymes to separate Saccharomyces cerevisiae beta glucans. A mixture of β-glucanase and protease enzymes was used to treat yeast cells (Din et al., 2018). Through process improvement, the extraction of beta glucans was maximised while the extraction of other cell components was reduced. Health supplements and pharmaceuticals explored high-purity beta glucans with immunomodulatory properties (Bobade et al., 2022).

Enzymatic Mushroom Extraction: Enzymatic extraction of beta glucans from medicinal mushrooms like Ganoderma lucidum was done separately (Alzorqi et al., 2017). Cellulase, hemicellulase, and β-glucanase enzymes treated mushroom biomass. Tested antioxidant and immune-boosting capabilities of beta glucans from the process. Enzymatic mushroom extraction produces these chemicals.

To summarise, enzymatic extraction of beta glucans is a modern, efficient, and durable method. The technique's scalability, specificity, and safety appeal to research and industry. Successful case studies show it can create intact, bioactive, high-quality beta glucans for food, drugs, and nutraceuticals.

3.1.2.4 Comparative Analysis

Comparing molecular extraction methods shows advantages and disadvantages (Mahmoud et al., 2021). Hot water extraction of beta glucan from cereal grains is simple and effective, however purity and composition vary. Acid and alkaline extraction methods are efficient, but wasteful, and require exact chemical.

The Enzymatic extraction process is more selective and environmentally benign than conventional methods, although it takes longer and costs more (Yuan et al., 2019). Modern extraction techniques are replacing or supplementing these traditional methods, which helped us understand beta glucan structure and functions.

Table 2: Comparison of Traditional Molecular Extraction Methods

Extraction Method	**Advantages**	**Limitations**
Hot Water Extraction	- Relatively simple and cost-effective	- Variability in purity and composition of extracts
	- Widely used for isolating beta-glucan from cereal grains (Dimopoulos et al., 2020).	- Requires careful temperature and time control
	- Minimal environmental impact compared to chemical methods	- Potential for degradation of bioactive compounds

Acid and Alkaline Extraction	- High extraction efficiency	- Harsh chemical conditions require careful control
	- Effective for breaking down cell wall structures	- Generates waste streams that require disposal (Goudar et al., 2020).
	- Established method with predictable outcomes	- Risk of polysaccharide degradation
Enzymatic Extraction	- Selective and environmentally friendly	- Higher operational costs
	- Preserves bioactivity of beta-glucan	- Longer processing times
	- Biodegradable enzymes from renewable sources	- Enzyme costs and availability

Applications and Future Perspectives: Kaur et al. (2019) found that traditional molecular extraction methods have given beta glucan for culinary, medicinal, and cosmetic applications. These methods provide health-promoting beta-glucan for cosmetics, medicines, nutritional supplements, and meals. Future demand is for sustainable, effective extraction methods that reduce environmental impact and improve product quality. Modern extraction methods include enzyme-assisted, supercritical, and subcritical water. Modern methods optimise beta glucan yield, purity, and bioavailability to meet consumer and regulatory requirements.

Singla et al. (2024) stated that standard molecular extraction methods can analyse and use beta glucan from natural sources. Despite their effectiveness, these methods rely on harsh chemical treatments that might not meet the sustainability norms of modern industries. The extraction and applications of beta glucan are changing with sustainable and effective methods. These methods boost purity, yield, and sustainability.

3.1.3. Mechanical Methods

Singla et al. (2024) stated that Mechanical and chemical beta glucans can only be recovered from their natural sources using mechanical and chemical extraction methods.

Physical pressures break down cell walls and release beta glucans without harsh chemicals, making these methods ideal for bioactive and structurally intact applications.

3.1.3.1 Milling and Grinding

Chioru & Chirsanova (2023) found that milling and grinding biomass improves extraction surface area. These methods lower particle size and release beta glucans mechanically. Ball, hammer, and disc grinding methods exist (Varelas et al., 2016). With cylinder-spun spherical grinding media, ball mills process biomass. The hammer milling process grinds materials into tiny particles at high speeds. Biomass is crushed and sheared by rotating discs.

Benefits and Challenges:

- Milling and grinding increase biomass surface area and extraction. By reducing particle size and improving interaction between the biomass and the extraction methods' beta glucans, these methods increase yield and recovery (Bobade et al., 2022). Cheap, simple, and efficient industrial milling and grinding. They are versatile biomass sources that can be used in different extraction settings.
- Also hard are milling and grinding. Mechanical operations can heat beta glucans and other delicate macromolecules. Bioactivity and usefulness of isolated beta glucans may decrease with degradation. Multiple milling operations may be needed to reach the desired particle size, increasing processing time and energy use (Minerviniet al., 2022). Wear and tear from routine maintenance on milling machines raises costs and challenges in operation.

Examples & Applications:

- Milling and grinding methods vary by extraction process and source. Ball milling provides uniform, tiny particles for industry and research (Li, 2018). Because barley and oats have uniform particle sizes on solvent interaction, this method extracts beta glucans well (Liu et al., 2021).
- The food and feed sectors utilise hammer milling to process massive amounts of material due to its high throughput and efficiency. Produces a fine powder from

plant materials, particularly cereal grains, for chemical or enzymatic beta glucans extraction. High-speed rotating hammers cut biomass, making critical parts easier to remove (Mykhalevych et al., 2022).

- The food and pharmaceutical industries use disc milling. The beta glucans industry uses it to process grains and legumes into fine flours for functional meals and supplements. For consistent particle size distribution and high-quality products, the pharmaceutical industry uses disc milling to prepare raw materials for processing and formulation (Mejía et al., 2020).

3.1.3.2 Homogenisation

Homogenisation is a mechanical process that breaks cell walls and releases intracellular components in the extraction of beta glucans. High pressure creates cavitation and shear pressures that damage cells when biomass is forced through narrow passageways or valves (Mykhalevych et al., 2022). The process homogenises biomass and decreases particle size for extraction. High-pressure homogenisation and microfluidisation are prevalent. Fast biomass movement through microchannels generates shear stresses, whereas 2000 bar hydrostatic pressing pushes it.

<u>Challenges and Benefits:</u>

Extraction of beta glucans benefits from homogenisation (Łubek-Nguyen et al., 2022). Breaking cell barriers is beneficial. Beta glucans are produced in greater quantities as homogenisation breaks down even the strongest cell walls of yeast with high pressure and shear stresses. Beta glucans are destroyed by different extraction methods; however, this method protects their bioactivity by controlling the temperature (Fang et al., 2021). Homogenisation is useful for lab research and factory production due to its industrial scalability.

The homogenisation process has downsides. Drawbacks include high energy use. Breaking cells under extreme pressure and shear strains requires a lot of energy, increasing operational costs (Tian et al., 2019). Micro fluidizers and high-pressure homogenizers are costly and maintenance-intensive. The extraction process gets costlier and difficult. Finding the correct pressure-flow rate balance to maximise yield and protect beta glucans is another difficulty. Bioactive compounds and extraction efficiency can be mis-optimized.

<u>Examples & Applications:</u>

The extraction and processing of beta glucans involves homogenisation. The dairy industry spreads fat globules and stabilises them via high-pressure homogenisation (Nakashima et al., 2018). The release and recovery of beta glucans are improved by consistent cell wall disintegration during extraction.

Homogenisation provides delicate emulsions, suspensions, and other formulations in the pharmaceutical industry. Neuro-emulsions and liposomes containing beta glucans increase medication bioavailability and distribution by micro-fluidisation (Łubek-Nguyen et al., 2022). This method evenly distributes beta glucans in formulations, boosting efficacy and lifetime.

The food industry homogenises functional foods and supplements. Bioactive substances are easier to absorb into food when homogenisation releases beta glucans from plant components (Lante & Canazza, 2023). Homogenised oat extracts containing beta glucans promote immunity and cardiovascular health in drinks, baked products, and snacks.

Biotechnology and cosmetics conform. It aids in the extraction and purification of bioactive chemicals from microbial cultures, particularly yeast and fungus, which are rich in beta glucans in biotechnology (Bulmer et al., 2021). In creams, lotions, and serums, homogenisation enhances beta glucans' moisturising and soothing properties.

3.1.3.3 Ultrasonication

According to Zhu et al. (2016) ultrasonication is a mechanical extraction method that produces liquid cavitation bubbles. The rapid formation and rupture of these bubbles generates shear strains, localised heat and pressure, and cell wall disintegration, releasing beta glucans. In this process, probe or bath ultrasonication directly vibrates the biomass solution. Improved extraction of bioactive components such beta glucans (Varelas et al., 2016).

Challenges and Benefits:

Chioru & Chirsanova (2023) found that one of the ultrasonic uses is the extraction of beta glucans. Cell disruption is a big benefit. Cavitation rips cell walls with high shear pressure, producing more beta glucans than conventional extraction methods (Nakashima et al., 2018). With ultrasonication at low temperatures, beta glucans retain their bioactivity and structural integrity. To preserve bioactivity, remove beta glucans' heat-sensitive components at low temperatures. Scalable ultrasonic extraction works with other methods. Improve extraction alone or with various methods. Ultrasonication's simplicity and scalability make it perfect for academia and industry (Sourki et al., 2017).

Ultrasonication has positives and downsides. Although rare, uncontrolled localised heating can damage sensitive biomolecules (Mahmoud et al., 2021). In dense, viscous biomass suspensions, ultrasonic waves do not travel far. Ultrasound probes and baths are costly and maintenance-intensive. Optimise ultrasonic frequency, power, and duration for high extraction efficiency and low bioactive chemical degradation.

Examples & Applications:

Many industries employ ultrasonication in the extraction and processing of beta glucans. It enhances food industry plant bioactive component, mineral, and flavour extraction. Ultrasonic extraction improves functional food and supplement production from oat and barley beta glucans (Sofi et al., 2017). These products stimulate immunity and heart health.

Pharmaceutical components, such as beta glucans, are improved by liposomal formulations and nano-emulsions manufactured by the pharmaceutical industry using ultrasonication (Yuan et al., 2019). This method increases formulation stability and quality by equally dispersing beta glucans.

In yeast and fungi rich in beta glucans, biotechnologists use ultrasonication to extract bioactive chemicals. Ultrasonication spreads beta glucans in lotions, serums, and creams to soothe and moisturise skin from the cosmetics industry.

3.1.3.4 High-Pressure Processing (HPP)

According to Mejía et al. (2020) HPP is a non-thermal mechanical extraction method that processes biomass in water at 100–600 MPa. More beta glucans are released throughout the process, which also alters cell structure. HPP presses biomass uniformly in water-filled pressure chambers. The structural integrity and bioactivity of bioactive compounds like beta glucans are preserved when cell walls are broken down by high pressure (Dimopoulos et al., 2020).

Benefits and Challenges:

HPP helps extraction of beta glucans. Beta glucans' low heat process preserves bioactivity and nutrients. Aids heat-sensitive chemicals. HPP disintegrates cell walls and produces beta glucans to improve extraction (Bai et al., 2021). HPP requires no chemicals or solvents, making it eco-friendly.

HPP is limited. High pressures are limited by energy and equipment expenses. This discourages small enterprises by raising early investment and running costs. For thick or sticky biomass, pressure penetration depth might not function. Optimising biomass type-specific extraction pressure and duration maximises efficiency without compromising compound integrity (Goudar et al., 2020).

Applications and Examples:

The food industry employs HPP to increase the extraction of beta glucans from barley and oats. The improved bioactivity and nutritional value of beta glucans in these products improves heart and immune health (Alzorqi et al., 2017). HPP is used by the pharmaceutical industry to isolate and preserve bioactive components from microbes and plants for pure dietary supplements and drugs. HPP is extracted from the cosmetics industry and used in skin-soothing and anti-aging products.

Table 3: Comparison of Mechanical Extraction Methods

Mechanical Extraction Method	**Benefits**	**Challenges**	**Specific Examples and Applications**
Milling and Grinding	- Increases surface area, enhancing extraction efficiency. - Simple and cost-	- Potential heat generation can lead to thermal degradation of beta	- Ball milling: Pulverising biomass using spherical grinding media. - Hammer milling: High-speed rotating hammers crush and grind

	effective. - Suitable for various biomass materials.	glucans. - Multiple milling steps may be required to achieve desired particle size (Minerviniet al., 2022).	materials. - Disc milling: Rotating discs shear and crush biomass. - Applications in preparing plant materials and grains for further extraction processes.
Homogenisation	- Effective in disrupting cell walls and releasing beta glucans. - Preserves bioactivity due to controlled temperature. - Scalable for industrial applications.	- High energy consumption. - Significant equipment costs. - Requires optimisation of pressure and flow rates (Varelas et al., 2016).	- High-pressure homogenisation (HPH): Biomass subjected to high pressure (up to 2000 bar). - Microfluidisation: Biomass forced through microchannels at high velocity. - Used in the dairy industry for homogenising milk and in pharmaceuticals for preparing emulsions (Li, 2018).
Ultrasonication	- Efficient cell disruption with minimal chemical usage. - Can be performed at low temperatures, preserving beta glucan bioactivity (Tian et al., 2019).	- Potential for localized heating, which can degrade beta glucans. - Limited penetration depth in dense biomass suspensions. - Equipment costs and maintenance.	- Probe ultrasonication: Ultrasonic waves emitted directly into biomass suspension. - Bath ultrasonication: Biomass placed in an ultrasonic bath. - Used in food processing to enhance extraction of flavors and nutrients, and in nanotechnology for preparing nanoparticles.
High-Pressure Processing (HPP)	- Non-thermal method, preserving structural and functional integrity of beta glucans. - Effective in disrupting complex cellular matrices (Sourki et al., 2017).	- High equipment and operational costs. - Requires specialized pressure vessels and safety measures. -	- Batch HPP: Biomass placed in high-pressure chamber and subjected to uniform pressure. - Continuous HPP: Biomass flows through high-pressure system. - Used in the food industry for pasteurisation and extending shelf life, and in pharmaceuticals for sterilisation (Sourki et al., 2017).

3.2. Modern Techniques

3.2.1. Modern Molecular Extraction Methods

Modern beta glucan molecular extraction techniques have increased in efficiency, yield, purity, and sustainability (Goudar et al., 2020). Modern extraction methods include enzyme-assisted, supercritical fluid, and subcritical water. Advanced technology and molecular processing understanding improve beta-glucan extraction efficiency and sustainability in each approach.

3.2.1.1 Enzyme-Assisted Heat Extraction

Beta glucan sources such as cereals, mushrooms, and yeast can be extracted using enzymes. Beta glucan is released from cell walls by certain enzymes (Alzorqi et al., 2017).

Beta glucan ases, cellulases, and hemicellulases attack polysaccharide bonds in the cell wall matrix. In order to increase enzyme surface area, the first step in the process is to grind the ingredients into a fine powder (Din et al., 2018). The material is suspended in water before enzymes were added. The reaction is moderate at enzyme-optimal temperature and pH. Beta glucan is delicately treated to preserve its structure and bioactivity for a pure product.

According to Zhu et al. (2016) the advantages of enzyme-assisted extraction over conventional methods are numerous. First, moderate operation minimises beta-glucan heat breakdown. By targeting cell wall matrix connections, unwanted component extraction is reduced. This process selectively increases beta-glucan production and purity. The eco-friendly process employs biodegradable waste and no harmful chemicals. Enzyme-assisted extraction is used in food and nutraceutical industries. Functional foods and supplements contain oat and barley beta-glucans, which promote immunity and decrease cholesterol (Venkatachalam et al., 2021). Beta glucan from enzyme-assisted extraction is pure and bioactive, making it attractive for many applications.

3.2.1.2 Comparative Analysis

Comparing modern extraction methods reveals gains in sustainability, yield, purity, and efficiency (Varelas et al., 2016). Enzyme-assisted, supercritical fluid, and subcritical water extraction preserve beta glucan bioactivity and structure at mild temperatures. Selectivity makes these methods produce pure beta-glucan with low contamination. Today, alternative rubbish disposal methods aid the environment. Supercritical fluid and subcritical water extraction use non-toxic, recyclable solvents, unlike enzyme-assisted extraction, which uses biodegradable enzymes (Sourki et al., 2017). The food, pharmaceutical, and cosmetic industries want sustainable production techniques.

Table 4: Comparison of Modern Molecular Extraction Methods

Extraction Method	Benefits	Limitations	Applications
Enzyme-Assisted Extraction	- Improved efficiency, yield, and purity of beta-glucan - Preserves bioactivity and	- Higher operational costs - Longer processing times	- Functional foods and dietary supplements - Pharmaceutical formulations

	structural integrity (Murphy et al., 2023). - Environmentally friendly with biodegradable enzymes	compared to conventional methods	- Cosmetic products
Supercritical Fluid Extraction	- High selectivity leading to high-purity beta-glucan - Operates under mild conditions preserving bioactivity (Tian et al., 2019).	- Requires specialized equipment - High initial investment	- Pharmaceutical applications - Nutraceuticals and dietary supplements
Subcritical Water Extraction	- Maintains bioactivity and structural integrity of beta-glucan - Uses non-toxic and recyclable solvent	- Limited scalability - Moderate operational temperatures may still require energy input (Bulmer et al., 2021).	- Food industry for functional ingredients - Biomedical and pharmaceutical applications

Applications: Modern extraction methods encourage innovation. According to Zhu et al. (2016) companies are adding beta-glucan to foods and supplements to attract health-conscious consumers. Beta glucan is included in several immune-boosting and wound-care medications. Cosmetic superfood beta-glucan moisturises and fights ageing. New extraction technology spurs product innovation. Businesses are studying beta glucan bioavailability, new health and wellness applications, and better extraction methods. University partnerships and research advance beta glucan research (Venkatachalam et al., 2021).

3.2.2. Ultrasonic-Assisted Extraction

Singla et al. (2024) stated that the modern chemical extraction technique for beta glucans is Ultrasonic Assisted Extraction (UAE). This method creates hot spots and microjets that break down cell walls and release chemicals by chemically cavitating the extraction solvent.

3.2.2.1 Different Ultrasonic-assisted Extraction Methods

Direct Ultrasonic Extraction: In a solvent containing ultrasound vibrations, direct ultrasonic extraction process extracts biomass (Dimopoulos et al., 2020). Cavitation destroys cells by causing large solvent temperature and pressure changes. By enhancing the diffusion of beta glucans from biomass into the solvent, this disruption quickens the extraction process. Direct ultrasound extraction delivers high yields immediately due to its simplicity and efficiency.

Ultrasonic-assisted Enzymatic Extraction: Ultrasonic assisted enzymatic extraction increases the extraction of beta glucans by combining the benefits of hydrolysis with ultrasound. Enzymes are used to selectively target and break down cell wall components while ultrasound increases substrate accessibility (Bobade et al., 2022). As ultrasound breaks down cell walls, fungus, algae, and cereals release β-glucans. For complicated biomass matrices, this method reduces enzyme use, processing time, and extraction efficiency.

Ultrasonic-assisted Solvent Extraction: Ultrasound improves solvent extraction via solvent penetration. Beta glucans are more quickly dissolved by cavitation, which breaks down cell membranes. This method retrieves beta glucans from plant fibres and lignocellulosic biomass with high structural complexity (Yuan et al., 2019). Since it reduces solvent consumption and extraction time while increasing solvent yield, ultrasonic assisted solvent extraction is a useful technique for lab and industrial settings.

3.2.2.2 Advantages of Ultrasonic Extraction

Alternative methods produce less beta glucans than ultrasonic assisted extraction. Beta glucans are released into the extraction solvent when ultrasound efficiently cracks cell walls (Liu et al., 2021). Biomass resource optimisation and industrial production cost reduction require yield.

Extraction Time Saved: Ultrasound speeds up the extraction process by increasing biomass-solvent mass transfer. Beta glucan extraction is quicker with CVI than with other methods. Industrial efficiency, throughput, and profitability rise with reduced extraction time (Mahmoud et al., 2021).

Efficiency-boosting extraction: Ultrasonic assisted glucan extraction improves by making biomass matrix beta glucans accessible. Microjets and shockwaves from cavitation damage cells, releasing chemicals into the extraction solvent. This method enables for a more thorough extraction of beta glucans while boosting bioactivity, purity, and biomass residual (Sourki et al., 2017).

Environment Sustainability: Ultrasonic solvent assisted extraction uses less solvent and energy than conventional methods. Waste reduction and resource efficiency lower ultrasound's environmental impact. Without damaging the environment, slow ultrasound processing protects beta glucans' structural integrity and bioactivity, creating high-quality extracts (Mejía et al., 2020).

3.2.2.3 Practical Applications and Examples:

Food and Nutraceutical Industries: According to Mejía et al. (2020) to extract beta glucans from grains like barley and oats, the food and nutraceutical industries frequently use the ultrasonic assisted extraction method. Beta glucans improve health by affecting cholesterol and immune system function. Fast ultrasound extraction yields pure beta glucan extracts for supplements and functional foods.

Applications in Biomedical and Pharmaceutical Sciences: Kaur et al. (2019) found that ultrasonic-assisted extraction allows pharmaceutical extraction of bioactive components from medicinal mushrooms like Ganoderma lucidum. Because of their improved bioactivity, beta glucans extracted by ultrasound are appropriate for immune-support and disease prevention formulations. The extraction process protects drug bioactivity.

Cosmetics and Personal Care Products: Singla et al. (2024) stated that the cosmetics industry extracts antioxidants and skin-healthy seaweed components using ultrasonic assisted extraction. Beta glucans extracted by ultrasound maintain their antioxidant and molecular integrity, benefiting skincare and anti-aging products. The moderate ultrasound extraction process maintains cosmetic bioactives.

In summary, extracting beta glucans from biomass sources using ultrasonic methods is sustainable and efficient. Ultrasound technique allows more efficient, faster, and yield-boosting extraction methods (Nakashima et al., 2018). Ultrasound-assisted extraction helps food, pharmaceuticals, and cosmetics. Ultrasonic bioactive component extraction will enhance for industry and academia.

Table 5: Comparison of Ultrasonic-assisted Extraction Methods

Ultrasonic-assisted Extraction Methods	**Description**	**Advantages**	**Practical Applications and Examples**
Direct Ultrasonic Extraction	Involves immersion of biomass in solvent and application of ultrasound waves to disrupt cell walls and enhance extraction efficiency (Li, 2018).	- Increased yield of beta glucans - Reduced extraction time - Simple and effective method	Extraction of beta glucans from barley and oats for dietary supplements and functional foods.
Ultrasonic-assisted Enzymatic Extraction	Combines ultrasound with enzymatic hydrolysis to improve accessibility of enzymes and enhance extraction efficiency (Din et al., 2018).	- Enhanced enzymatic activity - Reduced enzyme consumption - Efficient extraction from complex biomass	Extraction of beta glucans from fungi and algae for pharmaceutical applications (Yuan et al., 2019).
Ultrasonic-assisted Solvent Extraction	Uses ultrasound to improve solvent penetration and enhance mass transfer rates, accelerating beta glucan extraction.	- Improved mass transfer - Reduced solvent usage - High extraction efficiency (Goudar et al., 2020).	Extraction of beta glucans from lignocellulosic biomass and plant fibers for biorefinery applications.

Chapter 4: Health Properties

4.1. Safety

According to Du et al. (2019) beta glucans are polysaccharide molecules found in oats, barley, mushrooms, and yeast, among other sources. Modulation of the immune system, cholesterol reduction, and cancer prevention are all health benefits of these compounds. Understanding toxicity is crucial for customer safety with functional food ingredients and dietary supplements.

Biotoxicity investigations of beta glucans include in vitro, in vivo, and human models. In vitro cell cultures are commonly tested for cytotoxicity, genotoxicity, and immunomodulation with beta glucans (Bikmurzin et al., 2022). These studies reveal how beta glucans may harm cells and affect molecular activity.

Animals are used to simulate human exposure in controlled situations for toxicity assessment. These studies examine acute and chronic toxicity metrics like the LD50 (the dose at which half the population dies) and organ system effects. Beta glucans' low acute toxicity and high LD50 values provide them a wide margin of safety (Minerviniet al., 2022). Long-term toxicity studies show beta glucans do not harm health or organ function.

According to Kaur et al. (2019) human clinical trials are needed to apply preclinical findings. These studies examine the physiological benefits, safety, and tolerance of beta glucan supplements and better diets in humans. They can identify adverse responses and set dosage limits by assessing gastrointestinal tolerance, allergy potential, and systemic effects (Li, 2018).

4.1.1. Toxicity Studies and Safety Assessments

Analysis of toxicity and safety studies shows beta glucans' safety across study methods. Beta glucans have a moderate cytotoxicity and mild genotoxicity in vitro due to their biocompatibility and safe profile at physiological concentrations (Bobade et al., 2022). These findings illuminate beta glucans' beneficial impacts on cells and immune responses.

Animal research shows beta glucan's dangers and links them to human use. Multiple sources of beta glucans may have different toxicological characteristics due to structural and purity discrepancies (Mykhalevych et al., 2022). Beta glucans from yeast or fungi can cause allergic reactions, thus allergen labels and safety precautions are essential.

Beta glucans are safe to consume, according to human experiments. Different groups' beta glucan tolerance, gastrointestinal side effects, and physiological reactions are examined in these research (Liu et al., 2021). Clinical trials demonstrate beta glucans are safe and well-tolerated. This study is needed to reassure consumers and regulators that beta glucans are safe in dietary supplements and functional food additives.

4.1.2. Regulatory Standards and Implications for Human Consumption

Studies on beta glucan toxicity are important because these compounds are promoted for their health advantages. Consumers seek safety and regulatory safeguards while choosing beta glucans (Mejía et al., 2020). Studies have shown that beta glucans are safe as dietary supplements and functional food ingredients, especially for immunological support, cardiovascular health, and gastrointestinal function.

Beta glucans are safe to use in food and supplements worldwide thanks to regulatory authorities like the FDA and EFSA (Sofi et al., 2017). To assure product safety and efficacy, these organisations review toxicity data, purity standards, and production methods. Documenting extraction methods, quality control, and contaminant testing is required by laws to prevent beta glucan ingestion.

4.2. Cholesterol Lowering Effects

Beta glucans found in oats, barley, and mushrooms have many cholesterol-lowering methods.

Bile acids release beta-glucans. Bile acids, which breakdown and absorb food lipids, are made from cholesterol by the liver (Tian et al., 2019). The gut struggles to absorb beta glucans and bile acids. To make additional bile acids from cholesterol, this process lowers lipoprotein synthesis and serum LDL cholesterol.

Oat and barley beta glucans thicken the intestines and limit nutrient absorption. High viscosity hinders cholesterol absorption. Beta glucans' gel-like shape blocks intestinal nourishment (Bai et al., 2021). Postprandial cholesterol and lipids improve with delayed absorption.

Develop gut microbiota with beta glucans. Propionate and butyrate are produced from beta glucans by gut bacteria. SCFAs regulate cholesterol metabolism by increasing bile acid excretion and decreasing liver cholesterol synthesis (Łubek-Nguyen et al., 2022). Bacteria boost beta glucans' cholesterol-lowering effects and intestinal health.

Mejía et al. (2020) showed that beta glucans increase liver and intestinal bile acid and cholesterol excretion genes while decreasing cholesterol production and absorption genes. These gene expression changes lower LDL cholesterol, enhancing cardiovascular health.

4.2.1. Meta-Analyses and Clinical Practice Studies

Beta glucans reduce cholesterol in numerous groups, according to clinical research:

Clinical Trial Random Assignment: Several randomised controlled trials by Kaur et al. (2019) found that have explored beta glucans' impact on lipids. A 35-RCT meta-analysis in the American Journal of Clinical Nutrition found that beta glucans significantly lowered total and LDL cholesterol (Goudar et al., 2020). High doses of beta glucans (average 0.20 mmol/L) decreased LDL.

Observation and Time Studies: RCTs by Varelas et al. (2016) show beta glucan improves lipid profiles, and long-term observational studies confirm this. These studies demonstrate that ingesting beta glucans in food can lower total and LDL cholesterol and cardiovascular risk over time.

Analyses of Meta Data Meta-analyses show beta glucans lower cholesterol. Beta glucan supplements lower LDL cholesterol across cultures and cuisines. Higher doses of beta glucans reduce lipids more effectively, according to meta-analysis (Bulmer et al., 2021).

4.2.2. Implications for Cardiovascular Disease

Beta glucans enhance heart health and sickness prevention by lowering cholesterol:

Decrease Atherosclerosis Risk: Low LDL cholesterol lowers atherosclerosis. Beta glucans on bile acids reduce cholesterol absorption and increase excretion (Borchani et al., 2016). Plaque clearance enhances vascular function and lowers strokes and heart attacks.

Pressure Control: Beta glucans may lower blood pressure, another cardiovascular concern. This may improve endothelial function and vascular health, lowering CVD risk (Lante & Canazza, 2023).

Cardiovascular Disease Risk Reduction: To reduce cardiovascular risk, health agencies recommend beta glucans in a heart-healthy diet. Lowering cholesterol, blood pressure, and inflammation helps heart patients.

4.3. Immunomodulating Properties

Beta glucans, polysaccharides, have an immune system impact, making them essential in biomedical research and therapeutic applications. Natural sources include oats, barley, mushrooms, yeast, and seaweed to make these complex molecules (Nakashima et al., 2018). The biological function of these sources is influenced by structural configurations. Beta glucans bind immune pattern recognition receptors (PRRs) on cells, including complement and dectin-1.

These receptors' recognition of beta glucans trigger’s immune responses. In the respiratory burst process, they increase reactive oxygen species (ROS) and innate immune cells' phagocytosis. Increased activity removes pathogens and cell debris. Beta glucans increase cytokines, immune signalling molecules. They boost cytokine production, including IL-1, TNF-α, and IL-6, to help the immune system fight infections (Fang et al., 2021).

Beta glucans activate innate and adaptive immune systems. Transporting antigen helps dendritic cells activate and multiply T cells. For pathogen detection and defence, the adaptive immune system needs this connection (Alzorqi et al., 2017). Beta glucans boost Th1 cytokines and immunity in T helper cells. Beta glucans boost natural killer (NK) cells, which monitor cancer and virus-infected cells.

Beta glucans have therapeutic potential. Studies have explored immunocompromised patients, infection resistance, stress, and disease immune responses. Because they can alter immune responses without causing excessive inflammation, beta glucans provide intriguing therapeutic potential for treating autoimmune illnesses, allergy disorders, and other immune dysregulated conditions (Liu et al., 2021).

4.3.1. Immune Response Modulation Studies

Years of research have revealed the immunomodulatory and therapeutic potential of beta glucans. Preclinical research by Bulmer et al. (2021) suggests that yeast and beta glucans from fungi increase host defences against bacteria, viruses, and fungi. Pattern Recognition Receptors (PRRs) on immune cells activate pathogen-killing innate immune responses (Bobade et al., 2022).

Clinical trials reveal beta glucans' immunomodulatory effects. Beta glucan supplementation enhances immune system parameters in healthy and immunocompromised patients, according to Randomised Controlled Trials (RCTs) (Venkatachalam et al., 2021). Improved infection resistance, immune-regulating cytokines, macrophage and neutrophil activity. Meta-analyses of clinical data reveal beta glucans increase immune function in various populations.

4.3.2. Implications

Yuan et al. (2019) stated that beta glucans offer therapeutic promise in immune diseases. Polysaccharides increase immunity via interacting with immune cells.

Host Defence Improvement: Beta glucans increase natural immune responses. Beta glucans stimulate dendritic cells, neutrophils, and macrophages to phagocytose for immune coordination (Varelas et al., 2016). Improved immune function helps immunocompromised or chronically unwell persons.

Beta glucans can regulate immune system responses, rendering them therapeutic in autoimmune diseases when the immune system attacks healthy tissues. Studies suggest beta glucans affect immune homeostasis by influencing cytokine production and T cell responses. Modulation may reduce RA, MS, and IBD autoimmune reactivity (Sofi et al., 2017).

Beta glucans may treat cancer immunologically. To find and kill cancer cells, they enhance cytotoxic T and natural killer (NK) cells (Sourki et al., 2017). Beta glucans may improve cancer and immunotherapies by boosting the immune system's tumour response.

Golisch et al. (2021) believed that inflammation is caused by the immune system's reaction to harmless chemicals. Inflammation and tolerance may decrease adverse immune reactivity with beta glucans. Beta glucans may help allergic asthma, dermatitis, and rhinitis.

Protection of the Respiratory System Beta glucans improve asthma and COPD immune responses to the respiratory system. According to research, beta glucans reduce inflammation and boost respiratory pathogen immune defences to improve lung health and reduce infection frequency and severity (Mejía et al., 2020).

Stress and illness can weaken immune system. Infection risk, immune responses, and resistance are improved by beta glucans.

Beta glucans' immune system-influencing properties have led to new immunology applications. They are therapeutic prospects because they affect immune homeostasis, increase innate and adaptive immune responses, and prevent infections and cancer (Fang et al., 2021). More research is needed to understand beta glucans' methods of action, therapeutic efficacy, and potential uses in immune-related illnesses.

4.4. Quality of Nutrients

Nutritional quality of beta glucans affects diet and health. Beta glucans are polysaccharides comprised of glucose units joined by β-glycosidic linkages found in oats, barley, mushrooms, yeast, and seaweed, among other sources (Nakashima et al., 2018). It controls the immune system, gastrointestinal health, and cholesterol metabolism.

Soluble fibres increase the nutritional value of beta glucans. Nutritional absorption and digestion are limited by thickening intestinal contents. Fullness improves weight and blood sugar management (Mahmoud et al., 2021). Beta glucans' cholesterol-lowering effects have spurred research. They decrease serum cholesterol and promote cardiovascular health by binding to intestinal bile acids.

4.4.1. Impact on overall Diet and Health

Food sources contain beta glucans, soluble dietary fibres that affect health (Yuan et al., 2019). A diet rich in beta glucans is beneficial to health. Beta glucans increase seaweed, mushroom, barley, and oat nutritional value. For a healthy digestive system and fullness, these sources contain soluble fibres, minerals, and vitamins (Dimopoulos et al., 2020).

Beta glucans for cardiovascular health lower LDL cholesterol. Beta glucans bind intestinal bile acid to prevent heart attacks and strokes (Alzorqi et al., 2017). The diet should include foods rich in beta glucans for cardiovascular health. Beta glucans produce a colonic gel that regulates blood sugar. This limits carbohydrate digestion and absorption after meals to regulate blood sugar. The property helps diabetics and at-risk people.

Beta glucans, which are water-soluble, promote gut health and regular bowel motions. Prebiotics boost the immune system and digestion (Din et al., 2018). Gut microbiota imbalances affect mood, immune response, and health.

Beta glucans can help to lose weight by encouraging fullness and reducing hunger. Beta glucans slow down stomach emptying and delay appetite, making it easier to maintain a healthy weight (Bikmurzin et al., 2022).

Beta glucans alleviate oxidative stress by neutralising free radicals. Improved cellular health from antioxidant activity may minimise inflammation-related chronic illnesses.

To maximise health benefits from beta glucans, consume high-dose sources. Consume seaweed, mushrooms, oats, and barley. Beta glucans are in diet supplements and functional meals for easy intake (Venkatachalam et al., 2021).

4.4.2. Comparison with other dietary fibres

According to Wang et al. (2017) beta glucans are distinctive among dietary fibres due to their health benefits in general diet and dietary recommendations:

Oats, barley, and mushrooms contain soluble beta glucans. Postponing food digestion lowers cholesterol and blood sugar. Digestive gels are also made from fruit pectins, seed gums, and seaweed gums.

Beta glucans decrease cholesterol. Keep intestinal bile acids in to lower LDL. Beta glucans' cardiovascular health benefits make them a viable method for dietary cholesterol management (Bikmurzin et al., 2022). More soluble fibres like guar gum and psyllium husk decrease cholesterol by modulating lipid absorption and bile acid metabolism.

Gel-forming beta glucans control glucose. Beta glucans slow carbohydrate digestion, avoiding post-meal blood glucose increases. Fructooligosaccharides and inulin are soluble. They ferment and release short-chain fatty acids in the stomach, increasing glucose metabolism and insulin sensitivity.

Golisch et al. (2021) believed that beta glucans, prebiotics, nourish gut bacteria and boost health. Prebiotics improve digestive and immune health via Bifidobacteria and Lactobacilli growth. Dietary fibres such as plant cell walls, resistant starches in legumes and whole grains, and cellulose can assist maintain a healthy digestive system.

Beta glucans lower oxidation. These features may promote cellular health by reducing chronic inflammation (Minerviniet al., 2022). Fruit and vegetable flavonoids, flaxseed lignans, and antioxidant and anti-inflammatory diet fibres enhance health.

Table 6: Comparison with Other Dietary Fibres

Aspect	Beta Glucans	Other Dietary Fibres
Source	Oats, barley, mushrooms, seaweed	**Soluble Fibres:** Fruits (pectins), legumes (resistant starch), some vegetables (inulin, fructooligosaccharides) **Insoluble Fibres:** Whole grains (cellulose), seeds (gums), nuts (lignans) (Li, 2018)
Solubility	Soluble; forms viscous gels in the digestive tract	**Soluble Fibres:** Form gels aiding in digestive health and satiety **Insoluble Fibres:** Promote bowel regularity
Cholesterol-Lowering Effects	Binds bile acids, promotes excretion, lowers LDL cholesterol levels	**Soluble Fibres:** Bind bile acids, alter lipid metabolism, and promote cholesterol excretion
Blood Sugar Regulation	Slows carbohydrate digestion, regulates blood glucose levels	**Soluble Fibres:** Slow glucose absorption, improve insulin sensitivity (Murphy et al., 2023)
Prebiotic Effects	Nourishes beneficial gut bacteria (e.g., Bifidobacteria, Lactobacilli), supports gut microbiome health	**Soluble Fibres:** Ferment in the colon, support growth of beneficial bacteria
Antioxidant and Anti-inflammatory Effects	Exhibits antioxidant properties, scavenges free radicals, reduces oxidative stress	**Soluble Fibres:** Lignans (flaxseeds), flavonoids (fruits and vegetables) also exhibit antioxidant and anti-inflammatory effects (Tian et al., 2019)
Insoluble Fiber Content	Contains some insoluble fiber components, promotes bowel regularity	**Insoluble Fibres:** Predominantly from wheat bran, cellulose, contributing to bowel health and regularity
Unique Benefits	Unique cardiovascular benefits through LDL cholesterol reduction; supports immune function via prebiotic effects; antioxidant activity	Diverse health benefits including glycemic control, satiety, bowel regularity, and anti-inflammatory effects
Examples	Beta glucans from oats and barley; mushrooms like shiitake	**Soluble Fibres:** Pectins (apples, citrus fruits), resistant starch (beans, lentils) **Insoluble Fibres:** Cellulose (whole grains, vegetables), lignans (flaxseeds) (Din et al., 2018)

Chapter 5: Present and Future Trends

5.1. Emerging Applications

5.1.1. Focus on Applications as Prebiotics

According to Philippini et al. (2019) beta glucans are polysaccharides found in sources such as oats, barley, mushrooms, and yeast that are prebiotics. This non-digestible food component boosts gut flora for host health. Beta glucans and other prebiotics improve gut health by promoting good bacteria (Venkatachalam et al., 2021).

5.1.1.1 Action Mechanisms

Beta glucans ferment in the colon, making them prebiotic. According to Sivieri et al. (2022) beta glucans are digested by colon bacteria, unlike other carbohydrates in the small intestine. Throughout this process, digestive enzymes break down beta glucan molecules into monosaccharides and oligosaccharides. These smaller molecules ferment into SCFAs acetate, propionate, and butyrate.

SCFAs are energy sources for colonocytes that maintain colonic health. These germs increase Bifidobacteria and Lactobacilli and poison harmful bacteria by modulating gut pH (Carlson et al., 2017). Beta glucans stimulate the growth of healthy bacteria, which benefits the health.

5.1.1.2 Benefits for Gut Health

Beta glucans improve gut health by strengthening the immune system and gut barrier. They may be key dietary elements for intestinal health (Zhang et al., 2023).

Beta glucans promote intestinal barrier. The gastrointestinal epithelium lets food, diseases, and toxins in. Beta glucans boost mucin. Mucin protects intestinal epithelial cells from harmful pathogens and chemicals (Singla et al., 2024). Germ-blocking barriers reduce gut inflammation and promote gut health. Beta glucans in the diet boost mucin synthesis and reinforce the intestinal barrier, according to research.

Intestinal beta-glucans regulate immunity. The gut-associated immune system includes lymphoid tissue and immune cells (Caruso et al., 2022). Beta glucans bind to immune cell receptors on intestinal dendritic cells and macrophages. These interactions govern gut immune homeostasis by regulating cytokine and immunoglobulin production and immune responses. By changing the activity of immune cells and the production of cytokines, beta glucans improve gut health and immune tolerance.

Beta glucans may support gut flora. Zhu et al. (2016) found that colon bacteria make butyrate, acetate, and propionate SCFAs from beta glucans. SCFAs are energy sources for colonic epithelial cells and the gut barrier. SCFAs kill bad bacteria and promote Bifidobacteria and Lactobacilli by acidifying gut pH. Beta glucans improve GI health by balancing gut flora.

Growing research supports beta glucans' gut health advantages. Yuan et al. (2023) stated that beta glucans influence immune function and microbiota composition in clinical and experimental models. This implies that beta glucans as dietary supplements can improve gut health and lessen gastrointestinal issues. Future research on beta glucans will determine their gastrointestinal advantages and molecular processes to expand their therapeutic usage and eventual implementation into tailored diet plans.

5.1.1.3 Current Research

Much research has increased the understanding of beta glucans as prebiotics and their health benefits. Many clinical trials and meta-analyses show beta glucans enhance gut flora and reduce inflammation. A meta-analysis of clinical trials by Sridhar & Kaur (2023) indicated that beta glucans improve gut microbial diversity and reduce inflammation. Beta glucans may be therapeutic for metabolic syndrome and gastrointestinal illnesses, according Ringø & Song (2016).

Beta glucans' prebiotic process has been explored in recent research. According to Sivieri et al. (2022) beta glucans from sources such as oats, barley, mushrooms, and yeast can pass through the upper gastrointestinal system digestive process and enter the colon. Gut bacteria breakdown polysaccharides to make SCFAs such acetate, propionate, and butyrate. By regulating pH and promoting the growth of Bifidobacteria and Lactobacilli, SCFAs serve as energy sources for colonocytes and preserve health (Sridhar & Kaur, 2023). The fermentation process enhances gut health by altering GI immune responses and gut barrier function.

5.1.1.4 Applications for Companies

Biotech, food, and pharmaceutical companies like beta glucans for their health benefits (Mykhalevych et al., 2022). This polysaccharide is found in barley, oats, mushrooms, and yeast. Modern businesses use beta glucans in addition to prebiotics and probiotics.

5.1.1.5 Applications as Prebiotics

Beta glucans, a family of prebiotics, boost intestinal health. Oats, barley, mushrooms, and yeast are good sources of polysaccharides because they resist upper gastrointestinal digestion (Caruso et al., 2022). Fermentation by the intestinal microbiota produces SCFAs such butyrate, acetate, and propionate. SCFAs are crucial health and energy sources for colon cells.

Figure 2: Quaker Oats

Zhu et al. (2016) found that the prebiotic benefits of beta glucans depend on the colon's fermentation process. Beta glucans boost good bacteria. They increase Lactobacilli and Bifidobacteria and decrease harmful germs. Reduced inflammation, improved nutrient absorption, and intestinal barrier protection improve digestive health.

The food industry is promoting gut-healthy beta glucans such as Chobani Yogurt. They increase healthy bacteria in fermented foods including yoghurt, cereals, and diet supplements (Singla & Chakkaravarthi, 2017). Gut-friendly foods are in demand and improved nutritionally with this integration. Beta glucans as prebiotics are popular as the gut microbiota's health benefits are recognised.

Figure 3: Chobani Yogurt

Beta glucans' prebiotic properties are being used by companies to generate new formulations to satisfy client demand. Products containing beta glucans improve gut health (Zhang et al., 2023). Foods and snacks such as Barley Crackers containing beta glucans are well-liked by health-conscious customers seeking easy methods to eat more fibre and preserve healthy gut flora.

Figure 4: Barley Crackers

Research is being done on the prebiotic mechanism of beta glucans (Carlson et al., 2017). Studies demonstrate they improve gut immune responses beyond digestive health. Personalised nutrition and therapeutic uses of beta glucans are being researched to improve health and wellness.

Beta glucans as prebiotics are promising due to extraction and formulation advances. Companies may gain from beta glucans' gut health applications and health-conscious customers' altering diets as scientific understanding and consumer awareness develop. Market demand for functional foods and nutritional supplements that support gut microbiota health can be met by creatively adding beta glucans to foods and supplements (Venkatachalam et al., 2021).

5.1.1.6 Applications as Probiotics

Beta glucans enhance probiotic health. Polysaccharides aid gut microorganisms as prebiotics (Alzorqi et al., 2017). Beta glucans boost the efficacy of diet and supplements by promoting the proliferation of probiotic bacteria.

In appropriate levels, probiotics improve health. Supplements and fermented foods like yoghurt, kefir, and kimchi contain them. The digestive, immune, and metabolic systems are impacted by probiotic gut colonisation (Din et al., 2018). Effective probiotics require gut health.

Figure 5: Vitasoy's Fortified Oat Yoghurt

In came beta glucans. Microbes ferment nondigestible beta glucans in the colon. The fermentation process produces SCFAs such butyrate, acetate, and propionate. SCFAs are energy sources for gut health and colon cells (Venkatachalam et al., 2021). Lactobacilli and Bifidobacteria benefit from SCFAs' acidic conditions.

Beta glucans nourish probiotics. This interaction helps gut bacteria survive and colonise, promoting health. Probiotics and beta glucans may improve gut health, immune function, and disease risk.

Beta glucans and probiotics in formulations have been considered by the pharmaceutical industry. The formulations relieve IBS (Irritable-Bowel-Syndrome) and IBD (Inflammatory Bowel Disease), which are two distinct gastrointestinal disorders. Beta glucans and probiotics can induce immune responses and alter gut flora, improving symptoms and health (Bulmer et al., 2021).

Research on probiotics and beta glucans in tailored nutrition and preventative health care is underway. Probiotic beta glucans are becoming more stable and bioavailable due to formulation improvements to ensure efficacy from intake to gut colonisation (Lante & Canazza, 2023). By maintaining digestive health, this technique may treat metabolic and immune problems brought on by gut dysbiosis.

Functional foods and nutritional supplements can be made with beta glucans and probiotics to meet dietary demands.

Figure 6: Beta Glucan Supplement

Combining these methods lets businesses profit on gut-healthy product demand. Beta glucans and probiotics' complementary significance in therapeutic and preventative nutrition will grow as research and legislation improve.

Several industries employ beta glucans. Functional foods and diet supplements contain gut-healthy prebiotics. With probiotics, they increase microbiome-targeted medications. Extraction technique has enhanced their cosmetic and pharmaceutical applications (Łubek-Nguyen et al., 2022). The industry and consumers will be able to satisfy their changing needs thanks to increased research and innovation in this area, which will open up new possibilities for using beta glucans in personalised nutrition and therapeutic interventions.

5.1.1.7 Future Directions

Beta glucans as prebiotics are revived by biotechnology and customised nutrition. Biotechnology could make beta glucans prebiotics. Encapsulation technique protects beta glucans during digestion, ensuring their colon transit. Personal diets boost beta glucans' health benefits.

Future research must examine beta glucans' impact on gastrointestinal and immune health to determine their therapeutic potential. Beta glucans, gut microbiota, and host physiology may be linked by metabolomics and genetics (Murphy et al., 2023). Beta glucans may benefit metabolic regulation, immune modulation, and gastrointestinal health in this multidisciplinary approach.

5.2. Sustainable Production

5.2.1. Innovative and Green Extraction Methods

According to Varelas et al. (2016) eco-friendly extraction methods for beta glucans reduce environmental impact and sustainability. This section will examine various innovative industry approaches.

5.2.1.1 Subcritical Water Extraction

According to Morales (2023) subcritical water extraction, also known as pressurised 3.1, is a sustainable and innovative method for extracting bioactive compounds like beta glucans from natural sources. Using pressures above its boiling point, between 100 and 374°C, this innovative technique uses water (Murphy et al., 2023). High temperature and pressure increase water's solvent capacity, making beta glucan extraction from oats, barley, and mushrooms effective.

<u>Mechanisms and Operational Principles:</u>

Pressurised water is the subcritical water extraction principle. Unlike organic solvent extraction methods, subcritical water reacts with solvents. Due to its increased density and lower dielectric constant, water dissolves polar compounds like beta glucans more easily at high pressures and temperatures (Mykhalevych et al., 2022). The method preserves solvent characteristics by keeping pressurised water liquid above its boiling point.

Benefits of Subcritical Water Extraction:

Varelas et al. (2016) stated that the characteristics of subcritical water extraction make it the best method for extracting beta glucans and other bioactive compounds from natural sources. More about its benefits:

Environment Sustainability: Because no organic solvents are employed in the extraction process, subcritical water extraction is environmentally friendly (Mykhalevych et al., 2022). Organic solvent emissions, waste, and soil and water contamination in conventional extraction methods are environmental issues. Using water as the extraction solvent under high pressure and temperature, subcritical water extraction successfully extracts beta glucans. The approach avoids hazardous waste and promotes sustainable food, pharmaceutical, and cosmetics programmes worldwide.

Use less power: Subcritical water extraction methods require less energy than organic solvent extraction. Organic solvent heating requires energy to extract bioactive compounds. Subcritical water flows at pressures and temperatures over 100–374 degrees Celsius, water's boiling point (Li, 2018). Beta glucans are more soluble in subcritical water, allowing heating-free extraction. Large-scale production is economically viable and sustainable since the process reduces energy consumption and production expenses for heating and maintaining extraction temperatures.

High Efficiency of Extraction: Subcritical water extraction can generate beta glucans with low degradation. Controlled extraction conditions, such as temperature and pressure, can enhance oats, barley, mushrooms, and other natural sources of bioactive compounds (Minervini et al., 2022). This method ensures that the extracted beta glucans retain their beneficial properties for food, pharmaceutical, and cosmetic purposes by maintaining the bioactivity and structural integrity of beta glucans. High extraction efficiency increases product production and decreases raw material waste, enhancing process sustainability.

Application adaptability: Subcritical water extraction is useful for various industrial uses because beta glucans are recovered from several sources. Effective extraction of bioactive compounds from plant and fungal sources increases formulation versatility. For functional foods, dietary supplements, cosmetics, and pharmaceuticals, beta glucans are extracted using these methods. Undercritical water extraction meets consumer demand for natural, bioactive compounds with health benefits with product variety and innovation (Alzorqi et al., 2017).

Products' Safety and Quality: Subcritical water extraction produces solvent-free, highly pure beta glucans. This method ensures food and pharmaceutical quality. Customer-friendly extraction methods. Solvent residues reduce health concerns about beta glucans extraction methods (Din et al., 2018).

<u>Examples of Industry Practice:</u>

Avramia & Amariei (2021) argued that subcritical water extraction removes bioactive compounds and is environmentally friendly, making it popular across sectors. Additional uses for this innovative extraction method:

The food and beverage industry add beta glucans from barley and oats using subcritical water extraction to improve nutritional content (Tian et al., 2019). Dietary fibres known as beta glucans are beneficial to digestion and health. Beta glucans can boost the fibre content of breakfast cereals, bread, and energy bars to meet gut health requirements.

By decreasing cholesterol and increasing satiety, beta glucans in breakfast cereals promote heart health. For long-lasting beta glucans and digestive benefits, consumers who are concerned about their health turn to nutritional energy bars (Łubek-Nguyen et al., 2022). In the food industry, subcritical water extraction protects nutritional content while maintaining quality and safety standards.

Avramia & Amariei (2021) argued that in the pharmaceutical industry, beta glucans and other bioactive compounds are extracted from medicinal plants and fungi using a method called subcritical water extraction. Impacted immune function and general health are potential plant extract therapeutic outcomes. Subcritical water extraction yields pure beta glucans for pharmaceuticals and nutraceuticals that treat immune disorders and chronic illnesses. This method extracts beta glucans, which is used to make immune-supporting supplements. Due to controlled subcritical water extraction, beta glucans' health advantages can be preserved in pharmaceutical formulations (Bulmer et al., 2021). This application illustrates that this method provides safe, effective pharmaceutical-grade extracts.

Avramia & Amariei (2021) argued that subcritical water extraction lets the cosmetics and personal care industry benefit from beta glucans' skin benefits. These anti-aging, anti-inflammatory, and moisturising compounds help lotions, creams, and serums. Extracting beta glucans from natural sources like mushrooms and adding them to cosmetics can meet customer desire for innovative and effective skincare components. Beta glucans are added to skincare products to hydrate and rejuvenate the skin's barrier, as well as to minimise inflammation and wrinkles. Bioactive beta glucans are maintained in our skincare formulations employing subcritical water extraction, boosting efficacy and client satisfaction (Venkatachalam et al., 2021). By applying the method's clean and strong extracts, cosmetics companies can create high-end skincare lines that appeal to the growing organic and natural cosmetics market.

Future Directions and Innovations:

Subcritical water extraction research will advance. The extraction process will be more efficient, scalable, and affordable thanks to research and technology (Murphy et al., 2023). New formulations and products exploiting beta glucans' bioactive qualities will continue to develop as extraction methods and technology advance.

Varelas et al. (2016) stated that subcritical water extraction is sustainable as well as environmentally friendly methods and cutting-edge technology. Investments in sustainable production methods like subcritical water extraction are meeting regulatory and market demands for ecologically friendly products. Due to consumer education on industrial processes.

5.2.1.2 Supercritical Fluid Extraction

According to Varelas et al. (2016) supercritical fluid extraction (SFE) employs CO2 as a solvent to sustain gaseous and liquid phases under certain temperature and pressure. This method removes beta glucans but leaves unwanted ones. Traditional organic solvents have negative environmental effects, whereas CO2 is free, non-flammable, and non-toxic. CO2 removal after extraction ensures residue-free product. In extracting beta glucans from heat-sensitive sources like mushrooms and yeast, SFE protects bioactivity and nutritional value (Mykhalevych et al., 2022).

Benefits of Supercritical Fluid Extraction:

These characteristics make supercritical fluid extraction (SFE) a popular method for recovering bioactive compounds like beta glucans from natural sources. Supercrystallic CO2 transforms from liquid to gas at set temperatures and pressures, employ this innovative technique (Li, 2018). Advantages of supercritical fluid extraction include:

Highly Pure and Selective: SFE allows you avoid unwanted compounds. Using supercritical CO2, which controls temperature and pressure, may improve the extraction of beta glucans (Alzorqi et al., 2017). Uncontaminated beta glucans meet pharmaceutical and food industry standards.

Concept of sustainability Solvent extraction methods are greener than SFE. Gaseous carbon dioxide (CO2) is a better solvent than organic ones since it is non-flammable, non-hazardous to human or environmental health, and abundantly available (Minervini et al., 2022). The extraction process's environmental impact is reduced by recycling SFE CO2. SFE does not heat-degrade like other extraction methods. From sources like mushrooms and yeast, heat-sensitive bioactive compounds like beta glucans can be isolated. By avoiding heat, SFE preserves the structural integrity and bioactivity of beta glucans from beta compounds.

No solvent is left after SFE with supercritical CO2. Extracting beta glucans without solvent residues decreases customer safety and quality issues. Lowering purification and streamlining downstream processes improves production efficiency.

SFE adapts to natural sources like yeast, fungus, and plant components. Producers and researchers can extract beta glucans from various biological matrices, enhancing the cosmetics, pharmaceutical, and food industry potential (Din et al., 2018). By changing the extraction conditions, beta glucans can be created and their quality can be increased for industrial and consumer use.

Operational effectiveness: Varelas et al. (2016) found that in comparison to conventional methods, supercritical fluid extraction is quicker and requires less processing. High-Throughput Extraction can save money and increase productivity by using the SFE process to extract beta glucans. Since SFE meticulously controls extraction conditions, beta glucans are always high-quality and powerful. Pharmaceutical and nutraceutical efficacy and regulatory compliance depend on this control. In competitive marketplaces, standardised extracts aid product development and marketing.

Applications in the industry:

Because it efficiently and environmentally removes essential compounds, Supercritical Fluid Extraction (SFE) is useful in many sectors (Carlson et al., 2017).

The pharmaceutical industry uses SFE to extract bioactive compounds from natural sources. Beta glucans from Reishi (Ganoderma lucidum) and Shiitake have been extracted using SFE in research. Due to their immunomodulatory characteristics in pharmaceutical formulations, beta glucans improve overall health and immune function. Since SFE eliminates organic solvents during the extraction process, purifying beta glucans for therapeutic use is easier (Zhang et al., 2023).

The nutraceutical industry employs SFE to extract bioactive components from plants and other natural sources for dietary supplements. To enhance cardiovascular health and immune function, beta glucans made from oats and barley using SFE are added to nutritional supplements (Singla et al., 2024). SFE's selectivity protects beta glucans' structural and functional properties, creating high-quality, health-promoting products.

Food sources can produce flavour compounds, antioxidants, and nutritional components by employing SFE. Beta glucans are isolated from barley and wheat bran for SFE food products such bread, cereals, and energy bars. One of these products' nutritional benefits is the fibre from beta glucans, which aids digestive health and satiety (Singla & Chakkaravarthi, 2017).

The cosmetics industry uses SFE to extract yeast and fungus bioactive compounds. These compounds moisturise, combat inflammation, and prevent ageing. Lotions, creams, and serums with these compounds moisturise, enhance skin health, and reduce inflammation (Caruso et al., 2022). Natural and effective skincare products made with SFE from beta glucans are popular due to their potency and purity.

SFE is used for soil, water, and air pollution extraction in environmental applications. VOCs (volatile organic compounds) and insecticides are eliminated from environmental samples using supercritical CO_2. Cleaner and more efficient than solvent-based extraction, this technique decreases hazardous waste and ecological impact with environmental sustainability.

Traditional medicine systems around the world increasingly use SFE for the extraction of bioactive compounds from plants and herbs. To preserve their natural profiles and therapeutic properties, researchers and businesses can utilise SFE to extract polyphenols, terpenes, and alkaloids from botanical sources (Mykhalevych et al., 2022). These extracts are used in herbal supplements, traditional treatments, and functional meals to meet global demand for natural and sustainable products.

5.2.1.3 Enzyme-Assisted Extraction

According to Varelas et al. (2016) enzyme-assisted extraction breaks down beta glucan-rich cell walls of sources using cellulases and hemicellulases. This method targets beta glucans to improve extraction. Enzymatic methods are less energy-intensive and environmentally friendly than chemical methods since they operate at moderate temperatures and pH. The extraction process is sustainable because enzymes are biodegradable (Sridhar & Kaur, 2023). The food industry commonly use enzyme assisted extraction to extract beta glucans from cereal grains and other agricultural by-products.

Enzyme assisted extraction is a practical method for extracting beta glucans from natural sources, using beta glucans' selectivity and efficiency to boost yields while lowering environmental impact. The enzymes cellulases and hemicellulases degrade beta glucan. Unlike mechanical or solvent-based extraction methods, enzymes target polysaccharide matrix linkages to liberate beta glucans in soluble form (Mykhalevych et al., 2022).

Enzyme assisted extraction is advantageous because it is gentle. Traditional chemical solvent methods employ harsh solvents and high temperatures, whereas enzyme-assisted extraction uses neutral pH and low temperatures. This preserves beta glucans' structural integrity and bioactivity while saving energy and waste (Li, 2018). The Enzyme Assisted Extraction process promotes sustainable food and pharmaceutical chemistry and production methods.

Enzyme assisted extraction improves the sustainability of the process by using biodegradable and reusable enzymes. Eco-friendly enterprises suggest enzyme assisted extraction since it lessens the environmental impact of industrial processes. Biocompatible enzymes limit enzyme activity, making isolated beta glucans suitable for food and pharmaceutical use (Murphy et al., 2023).

Beta glucans are extracted from oats, barley, and wheat bran by the food industry using an enzyme- assisted extraction process. These food scraps contain beta glucans that stimulate the immune system and lower cholesterol. By releasing beta glucans from grain cell walls with enzymes like cellulases and hemicellulases, producers can boost the nutritional value of food items (Tian et al., 2019). Beta glucans are extracted using enzyme- assisted methods and added to food, drinks, and nutritional supplements to improve gastrointestinal health.

Pharmaceutically useful bioactive compounds like beta glucans must be extracted using enzymes. Nutraceuticals and medicines for immune, cardiovascular, and metabolic health use extracts (Łubek-Nguyen et al., 2022). Enzymes sustain the bioactive components' potency and efficacy for therapeutic application in pharmaceutical formulations by providing moderate extraction conditions.

Sustainable and effective enzyme- assisted extraction of beta glucans from natural sources. According to Morales (2023) the food, pharmaceutical, and nutraceutical industries can benefit from enzyme-assisted extraction since it boosts yields and reduces energy and environmental impact. Enzyme-assisted extraction lets companies manufacture healthful, eco-friendly functional meals, dietary supplements, and medications as demand for natural and sustainable products develops.

Applications in Companies:

Varelas et al. (2016) stated that bioactive compounds such as beta glucans can now be recovered from their natural sources thanks to enzyme- assisted extraction. This adaptable and effective method is used in cosmetics, food, and pharmaceuticals.

Improve product creation and ideation:

The food industry can make goods with beta glucans thanks to enzyme- assisted extraction (Bulmer et al., 2021). Companies can extract polysaccharides from oats and barley for functional foods and diet supplements. These products promise improved digestive, cholesterol, and immune system health. Enzyme assisted extraction ensures that beta glucans maintain their bioactivity and nutritional content, making these products more appealing to health-conscious consumers.

Efficiency, cost, and supplier selection: Enzyme assisted extraction conserves resources and money. Traditional chemical extraction uses more energy than gentler methods (Venkatachalam et al., 2021). This optimises raw material consumption and lowers heating and chemical costs. Companies gain from increased yields of beta glucans, which promote output and profits.

Enzyme-Assisted Extraction Reduces Environmental Impact, Supporting Corporate Sustainability. Enzyme assisted extraction uses less energy and waste than solvent extraction methods. Closed-loop manufacturing is possible with enzymes' biodegradability and renewable sources (Carlson et al., 2017). Companies devoted to sustainable business practices might mark their products as eco-friendly to attract environmental concerned customers.

Regulatory Compliance, Consumer Trust Pharmaceutical and cosmetic firms prioritise product safety and regulatory compliance. Enzyme assisted extraction avoids the need for chemicals and solvents by employing natural, biocompatible enzymes to extract beta glucans (Zhang et al., 2023). The cleaner, purer extracts pass all quality and regulatory tests. Compliant beta glucans increase consumer confidence, market acceptance, and brand recognition.

Enzyme-Assisted Extraction lets companies enter new markets and expand existing product ranges. For wound healing and immune system support, pharmaceutical formulations contain beta glucans extracted using enzymatic methods. Beta glucans' moisturising and anti-aging characteristics make them popular in skin care. Companies can gain market share and a competitive edge by adapting beta glucan applications to consumer trends and health needs using enzyme-assisted extraction (Singla et al., 2024).

Research and development: New product ideas develop when enzyme and extraction methods advance. Companies engage in research to improve enzyme formulations and extraction technique to increase beta glucans' production, purity, and bioavailability (Caruso et al., 2022).

5.2.2. Obtaining Beta-Glucans from Food Industry By-products

According to Varelas et al. (2016) sourcing beta glucans from wine lees and brewer's yeast is an appealing method of extracting bioactive compounds while addressing environmental sustainability and environmental efficiency. During the winemaking and brewing processes, yeast and wine lees are often wasted (Alexandre, 2022). Their rich beta glucans are advantageous to cosmetics, pharmaceutical, and food products.

5.2.2.1 Wine Lees

Source and Composition:

According to Kokkinomagoulos & Kandylis (2024) using wine lees for the composition of beta glucans is a sustainable and economically advantageous method in the winemaking industry. "Wine lees," sedimentary deposits of yeast cells, grape skins, seeds, and pulp remnants, contain beta glucans. These compounds explain why wine lees boost health and the winemaking process (De Iseppi et al., 2020).

Lees form during the fermentation and ageing processes. Aged grape juice sediment forms lees. Varietal, fermentation, and winemaking methods affect wine lees (Genisheva et al., 2023). Dead yeast cells, grape skins, seeds, and leftover wine make up their complex organic structure.

Beta glucans in yeast cell walls are nutritional and physiological. Antioxidants, gastrointestinal health benefits, and immune responses make these polysaccharides popular outside winemaking (Caseiro et al., 2022).

Extraction Methods for Beta Glucans from Wine Lees:

According to Naziri (2016) beta glucans can be recovered from wine lees utilising various extraction processes, each with benefits in efficiency and product quality:

Beta glucans are released from yeast cells by cell-wall-breaking enzymes. This method retains the bioactivity and integrity of beta glucans by using neutral pH and mild temperatures (Chioru et al., 2023). Enzymatic extraction preserves wine lees components while concentrating on beta glucans.

Extracting Subcritical Water: Solubility and extraction of bioactive compounds like beta glucans improve above boiling point. Because organic solvents are avoided, this method saves waste and energy while being environmentally benign. Since subcritical water extraction preserves bioactivity throughout the extraction process, it is suitable for heat-sensitive compounds like beta glucan (Poulain et al., 2024).

Environmental Advantages of Wine Lees Utilisation:

Varelas et al. (2016) stated that the environmental and industry benefits of beta glucan extraction from wine lees are substantial. The early fermentation and ageing processes squander wine lees—grape skins, seeds, and yeast cells. Leachate and soil can pollute landfills if rubbish is not properly managed. Vineyards can minimise environmental difficulties by turning waste into nutrients and extracting beta glucans from wine lees (De Iseppi et al., 2021). Trash disposal and winemaking have less environmental impact.

Efficiency of Resources: Beta glucans and other beneficial compounds in wine. Due to their immune-modulating and cholesterol-lowering properties, among other health benefits, beta glucans are intriguing as functional components in food, pharmaceutical, and cosmetic goods (Poulain et al., 2024). Wineries save resources by reusing lee beta glucans. Reduce virgin raw material use and safeguard natural sources for sustainable resource management. A natural next step is applying circular economy principles to wine lees beta glucan extraction. According to these principles, waste products can be used in other production processes to reduce environmental effect and complete the resource cycle (Genisheva et al., 2023).

Applications and Economic Viability for Commercial Use:

Wineries can profit from beta glucans in wine lees. Due to consumer demand for health-enhancing products, functional additives in food, drink, dietary supplements, and baked goods are expanding significantly (Kokkinomagoulos and Kandylis, 2024). Promoting wine beta glucans as sustainable, natural, and all-natural boosts their nutritional value. Diversifying income helps wineries weather market changes and maintain financial stability.

Beta glucans assist winemakers in diversifying and weathering economic and market uncertainty (Baptista et al., 2023). Current infrastructure and fermentation and extraction process expertise can help wineries enter new markets. In pharmaceutical contexts, beta glucans from wine lees may boost immune function, expedite wound healing, and decrease cholesterol (Dimou et al., 2016). The cosmetics industry uses moisturising and anti-inflammatory bioactive compounds. By adding beta glucans, wineries gain market share and profit from the health and wellness industry.

Applications of Beta Glucans from Wine Lees:

The food industry emphasises wine lee beta glucans for health and function (Dimou et al., 2016). The oesophagus and colon can pass prebiotics and dietary fibres. Caseiro et al. (2022) argued that beta glucans are fermented in the colon to produce SCFAs such propionate, butyrate, and acetate. SCFAs give colon cells energy and improve gut health by balancing microorganisms. Beta glucans are prebiotics for digestion health. Bread, energy bars, cereals, and functional drinks contain beta glucans. These foods and drinks promote gut health and fibre. People seek healthful foods like beta glucan.

Bioactive wine lees beta glucans are employed in medications and nutraceuticals (Varelas et al., 2016). Beta glucans boost immune responses and function in the pharmaceutical industry (Baptista et al., 2023). For infections, allergies, and immune illnesses, they are added to therapeutic formulations. Beta glucans may improve heart health by lowering cholesterol. Beta glucans are used in nutraceuticals to boost health and reduce oxidative stress. Beta glucans' adaptability has led to innovative and health-enhancing pharmaceutical and nutraceutical uses.

Case Studies:

Case studies such as Varelas et al. (2016) have proven that the extraction and utilisation of beta glucans from wine lees are effective and applicable across disciplines. The beta glucans extraction process from wine lees uses enzymes. To boost production and purity while cutting processing time and energy, the company improved enzyme conditions (Naziri et al., 2016). For digestive health, probiotics and diet supplements used beta glucans. Similarly, Caseiro et al. (2022) argued that, wine lees can be used to create products that improve health.

Revolutionising processes: Beta glucans were identified by food and pharmaceutical businesses. Subcritical water and supercritical fluid extraction have been the focus of research to increase extraction efficiency and product quality (Poulain et al., 2024). These methods use eco-friendly solvents and working conditions to preserve beta glucans' nutritional content and bioactivity. Innovative extraction processes ensure beta glucan-enriched commodities' homogeneity and efficacy for varied uses. Case examples demonstrate the benefits of technology, process optimisation, and wine lees as a sustainable source of beta glucans (Genisheva et al., 2023).

Last, wine lees beta glucans have food, pharmaceutical, and nutraceutical uses. They are good to digestive system, immune system, and overall health since they are prebiotics, bioactive compounds, and dietary fibres (Alexandre, 2022). Beta glucan extraction process uses wine lees to reduce waste and increase environmental sustainability. Case studies show beta glucans' scalability and economic viability. Wine lees as a source of beta glucans might be improved through research and development in food extraction technology, which would enhance innovation and sustainability in the global food and drink industry.

5.2.2.2 Brewer's Yeast

Source and Composition:

According to Avramia & Amariei (2021) brewer's yeast is created during the brewing process by combining discarded yeast cells, malt, and hops. This combination contains a lot of beta glucans, polysaccharides with health-promoting properties. Beta glucans found in yeast cell walls boost immune system, digestion, and health.

The process of yeast turning carbohydrates to alcohol and carbon dioxide is known as sedimentation in the brewing industry (Gabrielle et al., 2022). Minerals and useful compounds are provided by leftover hops and malt. Brewer's yeast beta glucans' physiological properties help functional foods and nutraceuticals.

Extraction Methods for Brewer's Yeast:

Modern extraction technique isolates bioactive compounds from beta glucans in brewer's yeast while maintaining structural integrity and functional properties. The two most common methods for extraction are Enzyme-Assisted Extraction and Supercritical Fluid Extraction (Avramia & Amariei, 2021).

Enzyme-Assisted Extraction:

Enzyme Assisted Extraction breaks down yeast cells' walls. Beta glucans are released into the extraction solution when these enzymes disrupt the connections in the yeast cell wall. The method efficiently and selectively releases beta glucans without impairing bioactivity, making it highly recommended (Łubek-Nguyen et al., 2022). Enzyme assisted extraction uses less energy and has less of an environmental impact than more aggressive chemical extraction methods. Pure beta glucans with high extraction efficiency are suitable for industry.

Supercritical Fluid Extraction (SFE):

Supercritical Fluid Extraction (SFE) uses CO2 as a solvent at specified temperatures and pressures. This method's selectivity removes unwanted glucans, permitting beta glucan extraction from wild yeast. Without toxicity or flammability, CO2 dissolves beta glucans. CO2 can be easily removed after extraction, leaving beta glucans (Lante & Canazza, 2023). Unlike solvent-based methods, SFE reduces toxic waste and environmental damage.

Environmental Advantages:

The circular economy is supported by the use of brewer's yeast for beta glucan extraction, which has environmental advantages (Schmidt, 2022).

Cut Waste and Boost Efficiency: Brewer's yeast is the principal by-product of the beer brewing process. Removing brewer's yeast beta glucans makes this biomass usable. Landfilling and incineration decrease waste and environmental impact (Chiozzi et al., 2021). Beer companies may save resources by using circular economy principles and turning used yeast into new components.

Sustainable techniques in the brewing industry include using beta glucan extraction through sustainable processes. Stewardship helps breweries limit their environmental effect (Murphy et al., 2023). A closed-loop beta glucan extraction system uses brewer's yeast. Waste management costs are reduced and the brewery's environmental and CSR credentials improve.

Viability of Beta Glucan Extraction from Brewer's Yeast:

Reduce Waste: Eliminating yeast beta glucans reduces waste management costs for breweries. Brewer's yeast can be fermented into beta glucans without disposal.

Resources used more efficiently increase productivity and lower manufacturing costs (Mykhalevych et al., 2022).

Food, nutraceuticals, and cosmetics use brewer's yeast beta glucans. Biogenic compounds enhance nutritional and functional properties, appealing natural health consumers (Li, 2018). By accessing these markets, breweries can create cash beyond beer. Diversion enhances the brewing industry's economic resilience against market and seasonal demand variations.

Enhanced Competitiveness and Market Position: Adding the beta glucan extraction technique to brewing operations increases competitiveness by producing unique, value-added products made from beta glucan. Sustainable and innovative product development improve breweries' market share (Minervini et al., 2022). Their brand and business flourish by targeting environmentally concerned customers and partners.

<u>Applications and Potential Scalability:</u>

Brewer's yeast beta glucans' extraction process and scalability serve various industries:

Food Supplements Brewer's yeast beta glucans are a dietary supplement (Alzorqi et al., 2017). Immune system health is supported by popular drugs. Beer yeast beta glucans activate immune cells. Products for the immune system and overall health often contain them.

Functional drinks contain brewer's yeast beta glucans. Probiotic, energy, and fortified juices boost health. Beta glucans, which improve health beyond hydration, are added to these drinks' nutritional profile (Din et al., 2018). Functional beverages with beta glucans are popular with health-conscious consumers since they strengthen the immune system and overall health.

The cosmetics and personal care industry recognises brewer's yeast beta glucans' skin-soothing and rejuvenating properties. Creams, serums, and lotions moisturise, reduce inflammation, and renew skin (Venkatachalam et al., 2021). Beta glucans strengthen and protect healthy skin walls from environmental assaults. Everyone desires natural, effective beta glucans skin care.

<u>Extraction Techniques' Potential Scalability:</u>

Scalability of beta glucan extraction from brewer's yeast is essential. Breweries can increase production using Enzymatic and Supercritical Fluid Extraction (SFE) methods

(Bulmer et al., 2021). Improving these methods boosts extraction yields, product quality, and consistency. Scalability helps breweries meet demand by adjusting to market and technical changes.

Beta Glucans Market and Technological Developments: Beta glucans and other naturally occurring components are required as people become more health conscious. Brewer's yeast meets client demands for transparent packaging and ethical production with sustainable beta glucans (Venkatachalam et al., 2021). The manufacturing of beta glucan is now more efficient and sustainable because to improved extraction procedures.

In summary, beta glucans from brewer's yeast are used for their immune-boosting, skin-soothing, and functional properties. Cosmetics and diet supplements benefit from beta glucans. By scaling extraction processes, breweries can satisfy increased demand without sacrificing quality or sustainability (Alzorqi et al., 2017). With improved health extraction methods and new technologies, brewer's yeast beta glucans could become useful additives that appeal to worldwide health and wellness trends. Sourcing beta glucans from wine and brewer's yeast is economic and sustainable (Alexandre, 2022). Using innovative methods to properly dispose of these leftovers high in beta glucans provides environmental and economic benefits. Using by-products for beta glucan extraction encourages sustainable practices and innovative product creation across numerous industries as customer demand for natural and functional ingredients develops (Schmidt, 2022).

Chapter 6: Conclusive Remarks

This comprehensive research on beta glucans from numerous sources reveals molecular structures, biological activities, and uses. Yeast, seaweed, barley, oats, and mushrooms contain beta glucans. The molecular composition, particularly β(1→3)and β(1→6) linkages, considerably impacts solubility and biological functions.

Beta glucans are widely sought compounds due to their flexibility and health benefits. The major purposes of these dietary fibres are satiety and digestive health. Beta glucans lower cholesterol and cardiovascular disease risk. Beta glucans boost cardiovascular health through bile acid binding and cholesterol absorption processes.

Beta glucans' immunomodulatory properties were also highlighted in the thesis. These properties boost immune system cytokines, macrophages, and natural killer cells. Immunomodulation has therapeutic potential for infections, inflammatory diseases, and cancer. Since they are immunomodulators and dietary fibres, beta glucans are powerful bioactive compounds with various health effects.

The thesis thoroughly examined the modern extraction technique for beta glucans, focusing on both ancient and new methods of extraction. Traditional chemical extraction and mechanical extraction methods have advantages and disadvantages. Using solvents in chemical methods to generate beta glucans has an environmental impact and requires careful safety standards. Sustainable extraction methods include enzymatic and ultrasonic assisted. Enzymatic extraction uses enzymes like cellulases and hemicellulases to remove beta glucans from cell walls with minimal energy and environmental impact. Ultrasonic assisted extraction destroys cell structures for speed and quality.

Beta glucans are used in industry and for health. Beta glucans are utilised in the food industry to improve nutritional profiles and digestive health. Beta glucans are added to pharmaceutical formulations for immune support, wound healing, and chronic disease therapeutics. Cosmetics and personal care use beta glucans. Customers seeking natural and effective skincare will love these additions' moisturising, anti-inflammatory, and antioxidant properties.

6.1 Implications for the Scientific Community and Industry

This thesis investigates the safety, efficacy, and applications of beta glucans in the scientific community and industry. Scientific process growth and sustainable and economically viable manufacturing processes are examples. The scientific knowledge and health benefits of beta glucans were explained in this thesis. The thesis explains beta glucans' molecular structures and biological functions to promote them as functional components and dietary supplements. Research on toxicity and safety supports the safety profile of beta glucans. This comprehensive analysis enhances food, pharmaceutical, and cosmetic confidence and allows for regulatory approvals and customer acceptance. The thesis explores beta glucan research in novel contexts including gut health prebiotics. They may boost gut flora and improve digestive health, alleviating many modern dietary and health issues.

Modern enzymatic and ultrasonic-assisted extraction methods, as well as more traditional chemical and mechanical ones, have all been examined for efficacy. Excellent yield via enzymatic extraction with minimal environmental impact. Sustainability in beta glucan extraction promotes global environmental and resource preservation strategies.

This thesis examines commercially relevant wine lees and brewer's yeast beta glucans. These by-products, which are plentiful in beta glucans, are untapped sources that can be economically viable with suitable extraction processes. The strategy highlights the economic benefits of recycling these wastes into useful goods. Circular economy concepts reduce waste disposal costs, increase efficiency, and produce revenue. By exhibiting environmental commitment, sustainable methods enhance corporate earnings and CSR.

The adaptability and plasticity of beta glucan production are demonstrated by the thesis's scaling of extraction methods from small-scale enzymatic processes to large-scale commercial applications. To meet expanding demand, the food, pharmaceutical, and cosmetics industries need scalability. This scalable extraction process can help industry build consumer-desired products using natural, practical ingredients.

6.2 Recommendations for Future Research and Applications

Future beta glucans research should focus on a few critical areas. Current trends and findings suggest below research and application recommendations:

Future research should focus on optimising extraction processes to maximise production and purity of beta glucans while minimising environmental impact. Enzymatic extraction needs more research to improve efficiency and scalability. Sustainability is this method. Researchers may test new enzymes or enzyme combinations that target different sources of beta glucans, such as barley, oats, mushrooms, and yeast, to improve beta glucan yields.

The selective extraction and reduced solvent use of Supercritical Fluid Extraction (SFE) require research. Future research could optimise SFE parameters to recover beta glucan from several sources while maintaining batch-to-batch quality and activity. Hybrid extraction technique combining enzymatic and SFE methods may improve extraction efficiency and processing time.

Beta glucans and other natural food compounds like vitamins, peptides, and polyphenols should be studied together. Bioavailability and effectiveness of beta glucans may boost health benefits. Antioxidants like polyphenols can increase the immunomodulatory or cardiovascular properties of beta glucans.

Beta glucans and probiotics may boost colon health. Probiotics may boost beta glucans' prebiotic benefits by promoting gut bacteria development, enhancing digestive and immune system health. Future research may focus on the best formulations and ratios of beta glucans and probiotics to enhance these synergistic effects.

Improve Clinical Studies and Health Claims: Clinical trials are needed to prove beta glucans' scientific effects in health. Numerous trials have indicated its immunomodulatory and cholesterol-lowering properties, but further research is needed to substantiate these findings. Large-scale randomised controlled trials on beta glucans can help reduce cardiovascular risk, improve immune function, and treat metabolic diseases like diabetes. Beta glucans may have therapeutic benefits in food, nutraceuticals, and drugs. Exploring their effects on inflammatory disorders, skin health, and cognition may reveal new consumer markets. Faculty, industry, and regulators must work together to support health claims and navigate constraints.

Ecological Impact and Sustainability: Production and extraction of beta glucans are sustainable. Future research on extraction methods should focus on solvent, waste, and energy efficiency. Innovations in bio-refinery economic approaches, such as integrated valorisation of agricultural and food industry outputs and waste streams, may boost sustainability and profitability.

LCAs could help the beta glucan industry adopt more sustainable practices by revealing the environmental impact of our production processes. Business can't increase environmental responsibility or meet consumer demand for sustainable products without first determining if sustainable extraction technologies are economically viable and scalable.

Beta glucans represent a potential new frontier in health and technical research because they can be used as dietary supplements and in therapeutic treatments. A comprehensive foundation for future research and uses, the thesis highlighted beta glucans' health benefits.

Chapter 7. Case Study

Title: β-Glucan from Brewer's Spent Yeast (BSY) as a Techno-Functional Food Ingredient

7.1 Abstract

Gabrielle et al. (2022) investigate BSY (brewer's spent yeast) as a β-glucan source in this case study. BSY, a by-product of beer production, is unusual due to its high amount of β-glucan, a polysaccharide with important biological and physiological properties. This study analyses β-glucan extraction methods from BSY, concentrating on yield, purity, and functional properties. BSY-produced β-glucan has antioxidant, hypocholesterolemic, and immunomodulatory properties due to its β-(1,3) and β-(1,6) glycosidic linkages. Immune function, lipid metabolism, and oxidative stress may be improved by food health.

BSY-derived β-glucan enhances texture, stability, and moisture retention in various foods, such as dairy, bread, meat, and beverages. Consumers want healthier food, and fibre and calorie density improve nutritional profiles.

The study emphasises the economic and environmental advantages of using BSY for β-glucan extraction, supporting sustainable in the brewing industry. When employing BSY-derived β-glucan in functional foods and nutraceuticals, extraction processes and combination with other beneficial compounds want more research. According to research, BSY β-glucan could turn brewery waste into commercial goods for the food industry.

7.2 Introduction

The process of beer production is a complicated technique that has evolved from simple fermentation to modern industrial methods over thousands of years. During the brewing process, the iconic drink is created. Understanding this process can help find new uses for brewer's spent yeast (BSY) beyond disposal methods.

Wort—malted barley and water—begins beer production. Malted barley includes sugars that aid in the fermentation process. Boiling hops adds taste and bitterness. Cooled wort ferments with yeast. To manufacture beer, yeast ferments carbohydrates into alcohol and carbon dioxide, according to Farber and Barth (2019).

Brewing is a chemical process that produces unwanted chemicals. Like malt bagasse, brewer's spent yeast (BSY) is a substantial by-product. BSY brewing requires unfermented yeast cells. Industrial brewing processes produce large amounts of BSY with high biochemical oxygen demand, making disposal challenging (Liu, 2021).

BSY Significance: Breweries face environmental and economic BSY disposal challenges. Despite its possibly helpful compounds, traditional trash or animal feed is BSY. According to Onofre et al. (2017 BSY is a healthy macronutrient supply with 40-60% protein and 29-54% carbohydrates. Bioactive properties and economic potential set β-glucan apart from other nutrients.

Glucose molecules joined by β-glycosidic linkages form the polysaccharide β-glucan in yeast cell walls. The presence of β(1→3)and β(1→6) linkages impacts chemical structure solubility and biological activity (Teparić et al., 2020). In functional foods and nutraceuticals, BSY β-glucan is known for its immunomodulatory, hypocholesterolemic, and antioxidant properties (Bastos et al., 2022).

Using BSY as a source of β-glucan can reduce waste and increase sustainability in the brewing industry. Breweries can satisfy global sustainability and corporate responsibility goals by incorporating BSY and enhancing resource efficiency and profitability (Marson et al., 2020).

7.3 Objectives

In this case study, β-glucan produced from BSY is studied by Gabrielle et al. (2022) for its biological and technical properties as well as food industry applications. With little environmental impact, optimising extraction processes increases production and purity. The study investigates the potential benefits of β-glucan from BSY, such as promoting food quality and human health through functional food compositions.

To extract β-glucan from BSY's rigid cell walls, traditional and modern extraction methods are required. Mechanical disruption (milling or homogenisation), enzymatic hydrolysis, and chemical extraction (alkaline treatment) will be tested for β-glucan hydrolysis efficacy, scalability, and impact.

Characterising β-glucan involves solubility, rheology, structural properties, and molecular weight. This research is crucial for comprehending how β-glucan's functionality and suitability for food applications vary with different extraction methods.

The study investigates the techno-functional properties of β-glucan from BSY, including its potential as a fat substitute, texture adjuster, emulsifier, and solvent in food. In dairy, bakery, meat, and beverage applications, β-glucan enhances nutritional profiles, quality, and shelf life. BSY-derived β-glucan can turn brewery waste into food industry and environmental sustainability ingredients. This case study aims to expand scientific knowledge and practical utilisation.

7.4 Methods

Various methods for extracting β-glucan from brewer's spent yeast (BSY) require rupturing the yeast cell wall. Mechanical methods and non-mechanical approaches have advantages and disadvantages of their own in terms of efficiency, yield, and β-glucan properties.

7.4.1 Extraction Techniques

7.4.1.1 Mechanical Methods

Mechanical methods break yeast cell walls and release β-glucan.

High-pressure homogenisation normally breaks yeast cells. The process includes pressurising BSY in a small area, forcing cells to rupture from stress. Although it may take multiple rounds to release β-glucan, this method is successful and scalable (Tian et al., 2019).

Ultrasonic waves cause cavitation bubbles in BSY suspension, damaging cell walls with high pressures and temperatures. Compare to mechanical methods, ultrasound releases β-glucan gently and effectively. According to Zheng et al. (2019), shifting ultrasound parameters such as frequency and intensity can prevent β-glucan molecules from boiling and breaking.

7.4.1.2 Non-Mechanical Methods

Using chemicals or enzymes, non-mechanical methods crack yeast cell walls and release glucan. These approaches include:

Alkaline Extraction Procedure: Cell wall structures are disrupted by NaOH/KOH. Cell walls are hydrolyzed by alkaline solutions at 90°C, producing β-glucan. Impurities are removed during the extraction process by precipitating β-glucan with ethanol and filtering the liquid.

Using specific enzymes, hydrolysis and other enzymatic methods can selectively break down cell wall components. Endo- and exo-glucanases break down β-glucan linkages, releasing soluble fragments from leftover biomass. Enzymatic hydrolysis preserves β-glucan purity while processing gently (Marson et al., 2019). High yields may need enzyme optimisation and lengthier processing.

BSY glucan is broken down by acetic acid (CH3COOH) and hydrochloric acid (HCl). Glycosidic linkages are broken down by acidic hydrolysis, releasing glucan. If pH and processing duration are carefully controlled, acid extraction can prevent - glucan breakdown and offer safety (Mahmoud et al., 2021).

7.4.2 Characterisation

To evaluate the quality, purity, and suitability of β-glucan extracted from BSY for various applications, characterisation is important.

The β-glucan extracted from BSY relies on β-(1,3) and β-(1,6) glucosidic linkages for structural integrity and biological activity. According to Bacha et al. (2017), NMR, FTIR, and XRD methods can reveal the molecular organisation and conformation of β-glucan.

BSY extract's β-glucan content is compared to other components during purity testing. Both HPLC and gravimetric methods are capable of detecting β-glucan levels precisely.

For food and pharmaceutical uses, centrifuge and filter High-Purity Glucan to remove biomass and contaminants (Dimopoulos et al., 2020).

Solubility, viscosity, and functional properties of β-glucan depend on its molecular weight distribution. DLS and SEC calculate average molecular weight and polydispersity index. The behaviour of β-glucan in solutions affects its application as a thickening or stabiliser in food mixes (Marson et al., 2019).

The solubility of β-glucan is essential for its flexibility in food items. Turbidity and spectrophotometric methods determine solubility profiles at different pH and temperatures. Water-soluble β-glucan fractions can be easily incorporated into food matrices, although insoluble or alkali-soluble fractions may increase stability and viscosity (Bastos et al., 2022).

7.4.3 Technological and Biological Properties

7.4.3.1 Technological Properties

BSY-derived glucan improves food quality. β-glucan stabilises emulsions by reducing interfacial tension and avoiding oil-water separation. Amphiphilic β-glucan stabilises salad dressings and sauces by creating protective layers around oil droplets.

β-glucan improves the texture of dairy, bread, and meat products by producing viscoelastic gels under controlled conditions. The gel's fat-like properties boost mouthfeel. Its properties include water-holding and elasticity.

In low-fat diets, β-glucan can serve as a suitable fat alternative. By imitating fat's structural role, β-glucan maintains creaminess and mouthfeel while decreasing calories. Yoghurt, mayonnaise, and baked goods are examples of β-glucan applications in food (Sengul and Ufuk, 2022).

7.4.3.2 Biological Properties

β-glucan's immunomodulatory effects involve boosting immune responses by interacting with immune cells including macrophages and dendritic cells. Pathogen-fighting host-defense systems and immune system modulation are enhanced by innate immune activity. Studies reveal that β-glucan has immunomodulatory properties, affecting cytokine production and phagocytosis (Caruso et al., 2022).

As a nutritional supplement, β-glucan lowers blood cholesterol by binding bile acids in the gut, limiting reabsorption, and increasing excretion. Lowering cholesterol absorption helps heart health. β-glucan decreases cholesterol, making it a promising element for functional meals to treat hyperlipidemia and metabolic diseases, according to clinical trials and animal research.

In addition to scavenging free radicals, β-glucan reduces oxidative stress pathways, boosting its antioxidant properties. Antioxidants enhance health by shielding cells from oxidative damage. Bastos et al. (2022) discovered that β-glucan can lower oxidative stress markers in humans, suggesting its potential in anti-aging products and dietary supplements.

7.5 Results

7.5.1. Yield and Purity

BSY (brewer's spent yeast) glucan extraction methods affect yield and purity. Yields compare β-glucan production to raw materials. The purity of extracted β-glucan is determined by its absence of contaminants and other compounds.

Homogenisation and ultrasound are common mechanical methods due to their scalability and low cost. By destroying yeast cell walls, these approaches release β-glucan into solution. Research reveals that equipment design, process factors (pressure and time), and BSY composition affect yields (Tian et al., 2019). Large-pressure homogenisation generates moderate to high amounts of - glucan with acceptable purity for commercial use.

Non-mechanical methods include chemical extraction, enzymatic hydrolysis, and combinations thereof. BSY glucan is precipitated from alkaline extraction using sodium or potassium hydroxide solutions and neutralisation. The method of Bacha et al. (2017) and Pinto et al. (2015) effectively extracts β-glucan from yeast cell walls, but requires precise pH and temperature control for optimal yield and purity.

With enzymes like carbohydrases or proteases, yeast cell walls are selectively damaged during enzymatic hydrolysis. The method isolates β-glucan while preserving other components, resulting in purer extracts. Optimise enzyme concentration, pH, and incubation period to maximise β-glucan release using costly methods (Marson et al., 2019; Vaithanomsat et al., 2022).

Multiple extraction methods are compared to find the most yield- and purity-efficient. They utilise ANOVA or t-tests to identify differences between methods. Gabrielle et al. (2022) discovered that alkaline extraction produced more β-glucan, while enzymatic hydrolysis provided purer, less contaminated extracts for pharmaceutical use. β-glucan extraction challenges include BSY composition fluctuations affecting performance. Effects of yeast type, fermentation conditions, and post-fermentation treatments on β-glucan content and structure impact the extraction process. Scalable, affordable extraction methods are required for industrial production. Mechanical methods may boost scalability but reduce purity due to non-specific cellular damage.

7.5.2. Structural and Functional Properties

For its functional properties in food items, the structural properties of β-glucan extracted from BSY are significant.

Chain Length and Molecular Mass: Glycosidic linkages join β-glucan glucose polysaccharide. The molecular weight (MW) of β-glucan affects solubility and viscosity depending on the yeast source and extraction method. Viscous solutions help soups, sauces, and dairy. High-MW glucan provides thickening or stabilising properties.

Branches affect the β-glucan structure's function, including β-(1,3) and β-(1,6) linkages. High branching improves food texture and flavour by allowing glucan to store water and produce gels. Understanding structural aspects is essential for tailoring β-glucan for texture or moisture retention (Bastos et al., 2022).

The water solubility of β-glucan impacts its performance. Insoluble β-glucan forms preserve the structural integrity of food matrices, while soluble forms thicken liquids. Studies on β-glucan solubility in different extraction methods have studied its technological uses. According to Bachmann et al. (2021), the viscosity and elasticity of β-glucan affect its ability to stabilise emulsions, enhance texture, and improve food composition.

7.5.3. Biological Activities

Extracted BSY glucan may improve health, making it a beneficial food and pharmaceutical ingredient.

There is extensive research on the immunomodulatory effects of β-glucan. β-glucan triggers innate immune responses by interacting with receptors on immune cells including macrophages and dendritic cells. This link aids immune monitoring, cytokine production, and phagocytosis. Studies show that BSY glucan can stimulate immune responses in vitro and in vivo, suggesting its potential as an immunostimulant in functional foods and supplements (Geller et al., 2019).

A major biological function of β-glucan is to lower cholesterol and control lipid metabolism. In the gut, soluble β-glucan forms a gel-like substance that binds to cholesterol and bile acids, reducing absorption. This mechanism regulates blood lipids by excreting cholesterol. Clinical research indicates that BSY glucan from diet has hypocholesterolemic effects, indicating that it might be useful as a dietary supplement for heart health.

β-glucan possesses antioxidant and anti-inflammatory properties, lowering oxidative stress and free radical scavenging in cells. Its antioxidant properties minimise tissue inflammation and oxidative damage. Studies on the antioxidant properties of fruit and vegetable-extracted BSY glucan have shown promise in lowering oxidative stress-related illnesses and boosting health.

A comprehensive picture of β-glucan's biological activity is obtained by combining findings from various studies in Meta -analysis and Systematic Reviews. Experimental models and extraction methods are examined in these papers. Immunomodulatory, hypocholesterolemic, antioxidant, and other bioactive properties. In order to identify trends and the biological effects of β-glucan, meta-analytical approaches assess and evaluate aggregated data. Geller et al. (2019) found that β-glucan has hypocholesterolemic effects in a meta-analysis of clinical trials.

7.6. Discussion

A comprehensive analysis of brewer's spent yeast (BSY) extraction is required to address the comparative analysis of β-glucan extraction methods, technological applications in food products, and biological consequences.

7.6.1. Extraction Method Comparison

Yield, purity, scalability, cost-effectiveness, and environmental impact are BSY glucan extraction methods' efficiency and sustainability.

Mechanical methods like homogenisation and ultrasound provide the advantages of scalability and affordability. β-glucan from high-pressure homogenisation easily damages yeast cell walls. This method provides moderate to high quantities of β-glucan, making it suitable for large-scale industrial applications (Tian et al., 2019). By co-extraction of other cellular components, mechanical process methods can lower glucan purity and downstream processing costs.

Chemical methods like alkaline extraction activate and neutralise BSY to precipitate β-glucan. Alkaline extraction produces more β-glucan than mechanical methods, but pH and temperature must be controlled for production and purity. Environmental problems include waste management and residual contaminants in glucan that has been extracted using chemicals.

By selectively breaking yeast glucan cell walls with enzymes, Enzymatic Hydrolysis releases β-glucan without contamination. The method produces concentrated extracts for pharmaceutical and high-value food applications (Marson et al., 2019). Optimising enzyme concentration, pH, and incubation time for β-glucan release is a costly and complex process in enzymatic methods.

Due to their selectivity, enzymes are a sustainable alternative to chemical methods. Green chemistry minimises energy and environmental effect compared to chemical and mechanical methods (Wang et al., 2020). Sustainable β-glucan production from BSY demands maximising yield while avoiding waste and resource utilisation. Optimise extraction processes.

7.6.2. Applications in Food Products:

BSY-derived β-glucan can be used to make dairy, bread, and meat products due to its techno-functional properties.

Thicker solutions and gels made from β-glucan enhance the mouthfeel of dairy products. Chen et al. (2018) found that adding β-glucan to yoghurt improves texture, mouthfeel, and protein stability during storage. According to Perez-Quirce et al. (2021), β-glucan's viscosity improves ice creams' sensory qualities, extends shelf life, and prevents cheese from syneresis.

Glucan replaces fat throughout the baking process and conditions the dough. Marson et al. (2019) report that water binding improves dough texture and handling, making bread softer and fresher. -Better eating trends include diabetes-conscious consumers seeking low-fat bakery items without losing taste or texture.

According to Dimopoulos et al. (2020) research, β-glucan helps beef emulsions bind water and stay stable, increasing juiciness and reducing cooking losses. Including β-glucan in meat compositions enhances nutritional value by reducing fat and preserving flavour and texture. This programme leans meat without losing flavour or quality.

Besides food, β-glucan from BSY is utilised in nutritional supplements, beverages, and infant food. Immunomodulation and cholesterol-lowering properties make it useful in natural immune support and cardiovascular health industries (Bastos et al., 2022).

7.6.3. Biological Implications and Health Benefits

Targeting immune cells with receptors, β-glucan enhances innate immune responses such cytokine production and phagocytosis. Immunomodulatory effects improve immune health and defence mechanism. Dietary - glucan and supplements can strengthen the immune system.

In the intestines, soluble β-glucan forms viscous solutions that bind cholesterol and bile acids, limiting absorption. Clinical trials on β-glucan supplementation's impact on cardiovascular health and coronary heart disease risk were conducted by Geller et al. (2019), and the findings demonstrate a significant drop in LDL cholesterol levels. The FDA supports β-glucan in heart-healthy diets due to its cholesterol-lowering properties.

Araújo et al. (2015) found that β-glucan's antioxidant properties diminish oxidative stress, free radicals, chronic inflammation, and age-related diseases. These properties better function and protect cells from oxidative damage. The therapeutic potential of β-glucan for inflammatory illnesses including arthritis and IBD is increased by its antioxidant properties.

Chapter 8: Conclusion

This case study examines β-glucan's benefits in food industry and human health, analysing its extraction, characterisation, and applications from brewer's spent yeast (BSY).

High BSY yields and purity of β-glucan were obtained by extraction methods such as enzymatic hydrolysis, alkaline extraction, and ultrasound extraction. Enzymatic hydrolysis releases β-glucan and breaks down yeast cell walls, making it a useful and efficient method. The mix of β-(1→3) and β-(1→6) linkages gives BSY β-glucan its solubility and functional properties.

Technological application of BSY glucan has demonstrated flexible uses as a functional ingredient and fat alternative in food products such dairy, bread, and meat. It stabilises emulsions, enhances texture, and produces gels, increasing food quality and addressing demand for healthy, functional foods.

Biologically, - glucan enhances host defence mechanisms and innate immune responses. Anticholesterolemic properties lowered LDL cholesterol and bound bile acids, improving cardiovascular health. The antioxidant and anti-inflammatory properties of β-glucan may alleviate chronic inflammation and shield cells from oxidative damage.

Future Direction:

Additional research may be conducted to optimise the extraction, application, and health-promoting properties of BSY from glucan:

To maximise efficiency Information retrieval: Research should improve extraction processes to increase glucan production, purity, and bioactivity. Bioprocessing and enzymatic hydrolysis can increase production while lowering environmental impact.

Enhance Product Applications: Increasing the usage of β-glucan in functional foods, dietary supplements, and pharmaceuticals through food composition and delivery technique. Optimise β-glucan properties for stability and bioavailability to meet industry needs and incorporate into various products.

Health Benefits and Clinical Validation: Clinical trials are needed to confirm β-glucan's immune, lipid, and inflammatory healthy effects. Clinical evidence will support β-glucan product approvals and health claims.

Regenerative Economy for Long-Term Sustainability: Using BSY as a renewable β-glucan source increases brewery by-product value and decreases waste, supporting circular economy concepts. Future research should look into β-glucan production's environmental sustainability, including energy efficiency, waste management, and carbon footprint reduction.

Implications:

Benefits of BSY β-glucan extend beyond nutritional and health benefits. By reusing brewery leftovers, this study promotes sustainable practices in the food and beverage industry. Innovative biotechnological processes to optimise sources and reduce waste are in line with circular economy ideals.

Functional foods with β-glucan can help public health programmes reduce diet-related chronic diseases. Increased demand for β-glucan-rich products in the worldwide health and wellness industry is driven by customers seeking natural, functional ingredients that enhance wellbeing.

Food-extracted BSY glucan may enable sustainable food and pharmaceutical research. Continuous research and cross-disciplinary collaboration are necessary to maximise the health and environmental benefits of β-glucan from BSY. Using β-glucan's biological and technological benefits can make future food systems healthier and more sustainable.

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