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Review Article

Effect of different drying and grinding techniques on the physicochemical properties and biological activities of fungal polysaccharides

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Abstract: Fungal polysaccharides are a class of natural compounds with diverse biological activities, widely utilized in the pharmaceutical, food, and cosmetic industries. Their unique bioactivities, including immunomodulatory, antitumor, antioxidant, and antimicrobial properties, have made them a popular subject of research and application. The physicochemical properties, structural characteristics, and biological activities of these polysaccharides are significantly influenced by various processing methods, with grinding and drying techniques playing crucial roles in determining the final product's quality and functionality. Grinding techniques during the preprocessing stage significantly impact the particle size, solubility, viscosity, rheological properties, and bioavailability of polysaccharides. Methods such as ball milling and ultrasonic milling can alter the yield, molecular structure, and dissolution rate of polysaccharides. During drying, temperature parameters are key factors affecting the physicochemical properties and biological activities of fungal polysaccharides. Different drying methods, such as hot air drying, freeze drying, and spray drying, each have their advantages and drawbacks. Therefore, careful selection of grinding and drying processing methods is essential to ensure higher yields and better bioactivity of fungal polysaccharides during extraction. However, most research on polysaccharides focuses primarily on extraction and purification, often overlooking drying and grinding. This study aims to discuss and compare the principles of different drying and grinding processes and summarize their effects on fungal polysaccharides. The methods used during the preprocessing stage and the drying stage significantly impact the yield, physicochemical properties, and chemical composition of these polysaccharides. These findings provide valuable references for researchers and industry professionals, aiding in the selection of optimal methods to improve the reliability and stability of final products, thereby enhancing their application value.

Keywords: fungal polysaccharides; drying techniques; grinding techniques; physicochemical properties; biological activities

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1 Introduction

Polysaccharides are carbohydrates consisting of more than 10 types of polyhydroxyaldehydes or ketones[1]. These complex molecules, formed by glycosidic bonds, have significant molecular weight and can be sourced from plants, microbial cell walls, and animal cell membranes. In biological systems, polysaccharides play various critical roles, including signal transmission, immune regulation, and substance transfer. They influence material and energy metabolism, contributing to overall human health. Fungal polysaccharides, derived from the fruiting bodies, mycelia, sclerotia, and fermentation broth of fungi (such as *Cordyceps sinensis*, Shiitake mushroom, Reishi mushroom, Wood ear mushroom, *Trametes versicolor, Tremella fuciformis*). Fungal polysaccharides can be classified into different groups based on their structure (linear and branched); sugar composition (homopolysaccharides and heteropolysaccharides); and the types of bonds between the monomers (β-1, 3, β-1, 6, or α-1, 3 linkages). Edible fungi, especially mushrooms, are popular health foods due to their variety and rich nutrition. Different developmental stages, such as fruiting bodies, sclerotia, mycelium, and spores, are often used as dietary supplements. Mushrooms are rich in bioactive substances like polysaccharides, fiber, ergosterol, and also contain a wide range of nutrients, minerals, vitamins, and amino acids[2, 3]. Notably, fungal polysaccharides exhibit a range of beneficial activities, including immunomodulatory, anti-cancer, antioxidant, gastrointestinal protection, intestinal health promotion, neuroprotection, liver protection, and hypoglycemic and

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hypolipidemic activities[4].

In the processing of polysaccharides, operations such as preprocessing, extraction, purification, and drying significantly affect their final properties and biological activities. Preprocessing is the initial step in polysaccharide processing, aiming to break down complex structures for easier extraction. The grinding process is used to achieve the desired particle size and improve the solubility and bioavailability of polysaccharides, affecting molecular structure and dissolution rate. Chemical methods use solvents or acids to break down cell walls, while enzymatic methods employ enzymes to increase yield. After extraction, purification removes impurities and concentrates polysaccharides to achieve high purity for further applications. Common methods include ethanol precipitation, dialysis to remove small impurities via a semipermeable membrane, and chromatography to separate polysaccharides based on molecular size or affinity. Drying is crucial for the preservation and stability of polysaccharides, with the main goal being to remove water without degrading the polysaccharides. Common drying methods include hot air drying (HD), freeze drying (FD), and spray drying (SD), each offering different advantages in maintaining polysaccharide structure and functional activity. Selecting the appropriate grinding method during preprocessing and the suitable drying method significantly impacts the yield and various activities of fungal polysaccharides[5-7].

Currently, research on polysaccharides mainly focuses on the extraction and purification stages, exploring the effects of different methods on structural properties and biological activities as shown in Tables 1 and 2[8]. However, drying and grinding are critical stages in polysaccharide processing that are often overlooked, despite their unique impact on the quality and functionality of the final product. Unlike extraction and purification, which aim primarily at obtaining and refining polysaccharides, drying and grinding play important roles in determining the usability of polysaccharides in various applications. In general, while various drying methods have minimal impact on the primary structure of polysaccharides, they can alter their chemical composition, including the content of monosaccharides, proteins, and uronic acid, significantly affecting their biological activity. grinding is performed on raw fungal materials before polysaccharide extraction or further on the extracted polysaccharides to achieve finer particles. Both drying and grinding contribute to the efficiency of fungal polysaccharide extraction and help maintain some of their structural and biological activities (Fig. 1).

Table 1 Comparison of different drying methods on fungal polysaccharides affecting the functions of various indicators

Source	Drying technique	Yield	Uronic acid content	Molecular weight (kDa)	Monosaccharide composition	Functional advantages	Reference
P. ostreatus	FD, DAD	Untreated: (28.70 ± 0.71)%, DAD: (14.58 ± 0.58)%, FD: (22.75 ± 0.56)%	—	—	—	FD is more conducive to preserving the bioactive proteins and polysaccharides of *P. ostreatus*.	[23]
C. militaris	HD, ID, FD	ID: 3.61%, FD: 2.60%, HD: 2.19%	Uronic acid: FD: 26.55%, HD: 21.73%, ID: 20.55%	—	Neutral sugar: FD: 85.58%, HD: 73.23%, ID: 67.92%	Immunomodulatory, antioxidant, anti-tumor, and hypoglycemic pharmacological activities	[24]
P. eryngii	FD, OD	FD: (7.31 ± 0.15)%	Total phenol: (1.589 ± 0.117)%,	—	Glc: FD: 88.90%, OD: 87.68%; Man: FD: (5.75 ± 0.05)%, OD: (5.52 ± 0.41)%; Gal: FD: (5.34 ± 0.30)%, OD: (5.17 ± 0.02)%	Stronger ABTS radical scavenging activity in FD compared to OD	[25]
C. sinensis	FD	0.185%	—	—	—	Strong antioxidant activity	[26]
L. curvatus SJTUF 62116	FD	0.02%	—	4.43×10^4	Glucosamine, Glu, Man, glucuronic acid	Antioxidant, antitumor, promotes probiotic colonization, lowers blood sugar	[31]
L. fermentum S1	FD	—	No uronic acid	7.19×10^5	Man, Rha, glucose, galactose	Strong antioxidant activity, modulates oxidative stress in nematodes	[32]
C. militaris	HD, ID, VFD	HD: 2.19%, ID: 3.61%, VFD: 2.60%	FD: 26.55%, HD: 21.73%, ID: 20.55%	—	Neutral sugar FD: 85.58%, HD: 73.23%, ID: 67.92%	Immunomodulatory, antioxidant, antitumor, and hypoglycemic activities	[6]
A. auricula	HD, ID, FD, MD	FD: (94.06 ± 0.44)%, HD: (93.85 ± 0.31)%, ID: (96.74 ± 0.43)%, MD: (91.51 ± 1.15)%	FD: 33.53%, HD: 31.00%, ID: 24.33%, MD: 32.53%	FD: 4.07×10^5; HD:1.03×10^6 and 1.72×10^5; ID: 1.00×10^6 and 3.90×10^5, MD: 1.56×10^6 and 3.26×10^5	Galactose, glucose, Man, glucuronic acid, xylose	Strongest antioxidant activity in FD	[33]
Spent *L. edodes* substrate	FD, VD, SD	MD:13.00%, VD: 8.69%, SD: 10.68%	FD: (6.88 ± 0.09)%; VD: (0.43 ± 0.03)% SD: (0.41 ± 0.07)%	—	FD: Ara:Xyl:Man:Glc:Gal = 54:26:3:11:6	Highest yield and antioxidant activity in FD	[34]

(Continued)

Source	Drying technique	Yield	Uronic acid content	Molecular weight (kDa)	Monosaccharide composition	Functional advantages	Reference
Cs-4 fungus	FD	Extracellular polysaccharides: 6.95%, intracellular polysaccharides: 3.65%, purified extracellular polysaccharides: 2.87%, purified intracellular polysaccharides: 0.75%	—	—	EPSP and IPSP monosaccharide composition is mainly fucose, arabinose, galactose, Glu, xylose, Man, and Rib. Arabinose, galactose, Glu, and Man are the main monosaccharides	Significantly inhibit collagen-induced human platelet activation and aggregation, reduce CD62p expression and αIIbβ3 activity on platelet surface. EPSP, IPSP, and their metabolites can also inhibit thrombosis formation *in vivo*	[39]
T. fuciformis	US + MVD, USMVD, HD	Fresh: 9.42%, HD: 5.80%, MVD: 5.87%, US + MVD: 6.07%, 6.15%, 6.25%, USMVD: 6%, 6.35%, 6.75%	—	Fresh: 1.64×10^5, HD: 2.97×10^5, MVD: 187.92, US + MVD: 1.72×10^5, 1.94×10^5, 2.16×10^5 USMVD: 1.78×10^5, 2.10×10^5, 2.21×10^5	Mainly composed of fucose, arabinose, Rha, Glu, Man, and Xyl	Multiple bioactivities including antioxidant, anti-tumor, anti-aging, immunomodulatory, and hypoglycemic effects	[41]
L. edodes	HD, ID, VFD, IHD, PVD, RHD	IHD: 24.07%, RHD: 19.77%, PVD: 18.55%, HD: 16.24%, Fresh: 28.85%	IHD: (15.46 ± 0.78)%, RHD: (13.93 ± 0.31)%, PVD: (10.39 ± 0.56)%, HD: (7.72 ± 0.34)%, Fresh: (17.21 ± 0.89)%	—	—	IHD increases antioxidant properties	[47]
A. blazei LPB 03	FD, VD, SD	FD: 97.36%, VD: 93.23%, SD: 42.31%	—	—	—	Significant inhibition of Ehrlich tumor cell viability	[46]
T. fuciformis	CD (18 °C cold air), HD (50 °C), FD	FD: 15.35%, CD: 15.60%, HD: 16.10%	—	FD: 2.06×10^7; CD: 2.41×10^7 HD: 2.34×10^7	—	High thermal decomposition performance	[50]
Spent *L. edodes* substrate	FD, VD, SD	FD: 13.00%, VD: 8.69%, SD: 10.68%	FD: (6.88 ± 0.09)%, VD: (4.28 ± 0.32)%, SD: (4.13 ± 0.06)%	FD: 1.68×10^4	FD: Ara:Xyl:Man:Glc:Gal = 54:26:3:11:6	Antioxidant activity	[60]
Pleurotus geesteranus	VFD	Polysaccharide content: (83.23 ± 0.38)%	—	Number average molecular weight: 4.87×10^6, weight average molecular weight: 9.8×10^6	Fuc, Ara, Gal, Glc, Xyl, Man, Rib, Gal-AC, Glc-AC	Enhances body's antioxidant capacity, inhibits oxidative stress and inflammation, regulates lipid metabolism, reduces lipid accumulation, and regulates immunity through multiple signaling pathways (Keap1/Nrf2, AMPK/SREBP, TLR4/NF-κB)	[68]

2 Various drying and grinding techniques for fungal polysaccharides

2.1 Drying methods

Drying methods are essential for processing fungal polysaccharides, as they minimize nutrient loss, inhibit spoilage microorganisms, slow down enzyme activity, and reduce moisture-mediated reactions[9]. The impact of drying on fungal polysaccharides varies with the method used, each having distinct principles and effects.

Common drying techniques include natural air drying (ND), HD, FD, SD, vacuum drying (VD), microwave drying (MD), oven drying (OD), infrared drying (ID), radio frequency-assisted drying (RFD), desiccant air drying (DAD), infrared hot air drying (IHD), cold air-dried (CAD), relative-humidity drying (RHD), pulsed vacuum drying (PVD), heat pump drying (HPD), ultrasonic pretreatments with microwave vacuum drying (US + MVD), air-borne ultrasonic pretreatments combined with microwave vacuum drying (USMVD) and infrared accelerated drying (IRAD). These methods differ in efficiency, time requirements, convenience, cost-effectiveness, and environmental impact. FD is complex because freezing, sublimation, desorption, and rehydration all impact the final product's quality, with each stage applying different pressures[10]. HD is a fast and cost-effective method that allows for full control over process parameters such as temperature, drying time, and air speed. However, it often results in nutrient loss and diminished product quality[11]. MD offers lower shrinkage, better color, and higher rehydration capacity compared to HD. It significantly reduces drying time and production costs, although the quality of the products is influenced by drying parameters such as microwave power, drying time, initial water content, and dielectric properties of the material. VFD preserves the natural color, flavor, and nutrients of the product, but requires specialized equipment and is expensive. It is particular effective for high-value products where maintaining

Table 2 Comparison of different grinding methods on fungal polysaccharides affecting the functions of various indicators

Source	Grinding technique	Yield	Uronic acid content	Molecular weight (Da)	Monosaccharide composition	Functional advantages	Reference
Agrocybe aegerita	Ultrafine grinding	Chunk: (3.70 ± 0.06)% 40 mesh: (6.01 ± 0.48)% 100 mesh: (9.35 ± 0.21)% 300 mesh: (13.14 ± 0.10)%	—	Large: 4.24×10^5 Small: 1.29×10^4	—	Enhanced pharmacological activity	[27]
Phellinus baumii	Regular and ultrafine grinding	Regular: 0.97%, ultrafine: 4.48%	—	Molecular weight distributionrange: narrow in regular, wider in ultrafine	Glu highest, followed by Gal and Man, Fuc lowest	Immunomodulatory and antitumor activities	[28]
Auricularia polytricha	Ultrafine grinding	3 min: 11.0%, 20 min: 48.0%	—	—	—	Positive correlation between ultrafine grinding time and antioxidant capacity	[29]
L. edodes	Airflow ultrafine grinding	Ultrafine: 0.18%, 40 mesh: 0.11%, coarse: 0.10%	—	—	—	Enhanced powder flowability, water retention, and swelling capacity	[30]
G. lucidum	Ultrafine grinding	Highest yield at 1.5 h ultrasound: 5.61%	—	—	—	Higher concentration increases radical scavenging effect	[18]
A. auricular	Cyclone pulverizer, airflow pulverizer, ball mill pulverizer	Temperature 80 °C, time 5.5 h, material-liquid ratio 1:100, pH 5.5, polysaccharide yield 14.24%	—	Ultrafine powder polysaccharides purification results in three main components with relative molecular masses of 7.82×10^4 and 9.79×10^3	—	Ultrafine powder has a good lipid-lowering function	[35]
G. lucidum fruit body	Ordinary mechanical grinding, ultrafine grinding	After grinding, the polysaccharide content in extracts and ethanol precipitated crude polysaccharides increased significantly	—	—	Mainly contains Gal and Glc with small amounts of Fuc, Man, and GlcA	Clinically used for treating chronic bronchitis, neurasthenia, coronary heart disease, hyperlipidemia, hypertension, and leukopenia	[44]
G. lucidum	Superfine grinding technology (300 mesh)	2.46%	—	—	Man, Rib, Glc, Gal, and Fuc	Antioxidant activity	[45]
A. bisporus	Regular and ultrafine grinding (200 mesh)	Regular (100 mesh): (3.63 ± 0.02)%, ultrafine (200 mesh): (3.91 ± 0.02)%	—	—	—	—	[48]
Shiitake mushroom cap powder	Regular and airflow ultrafine grinding	—	Highest free phenol in airflow ultrafine: (0.45 ± 0.01)%, Lowest bound phenol: (0.03 ± 0.01)%	—	—	Strong antiproliferative activity	[49]
G. lucidum spore powder	Low-temperature ultrafine *vs* room-temperature mechanical milling	Higher polysaccharide content in UFG-L compared to MM-R	—	—	—	UFG-L has lower specific surface area but higher bioavailability compared to MM-R	[52]
Juncao antelope-shape *G. lucidum*	Regular grinding, Ultrafine grinding (100, 300 mesh)	Polysaccharide content: ultrafine: 2.17%, fine: 1.75%	—	—	—	Smaller particle size and increased cell wall breaking enhance release of polysaccharides and triterpenoids	[53]

quality is crucial. ID is considered an innovative drying solution for the food industry due to its energy-saving potential, reduced drying time, and cost-effectiveness. However, it has limitations such as poor penetration, overheating, and combustion risks[12]. To mitigate these issues, IRAD, which combines ID with other methods, has been developed. RFD is an emerging technology for drying food and agricultural products. It is characterized by rapid, uniform, stable, volumetric heating, high energy efficiency and water balance[13]. Appropriate drying methods are crucial for maintaining the integrity and functionality of fungal polysaccharides. In recent years, various drying methods have been applied to fresh vegetables, plants, and medicinal materials to

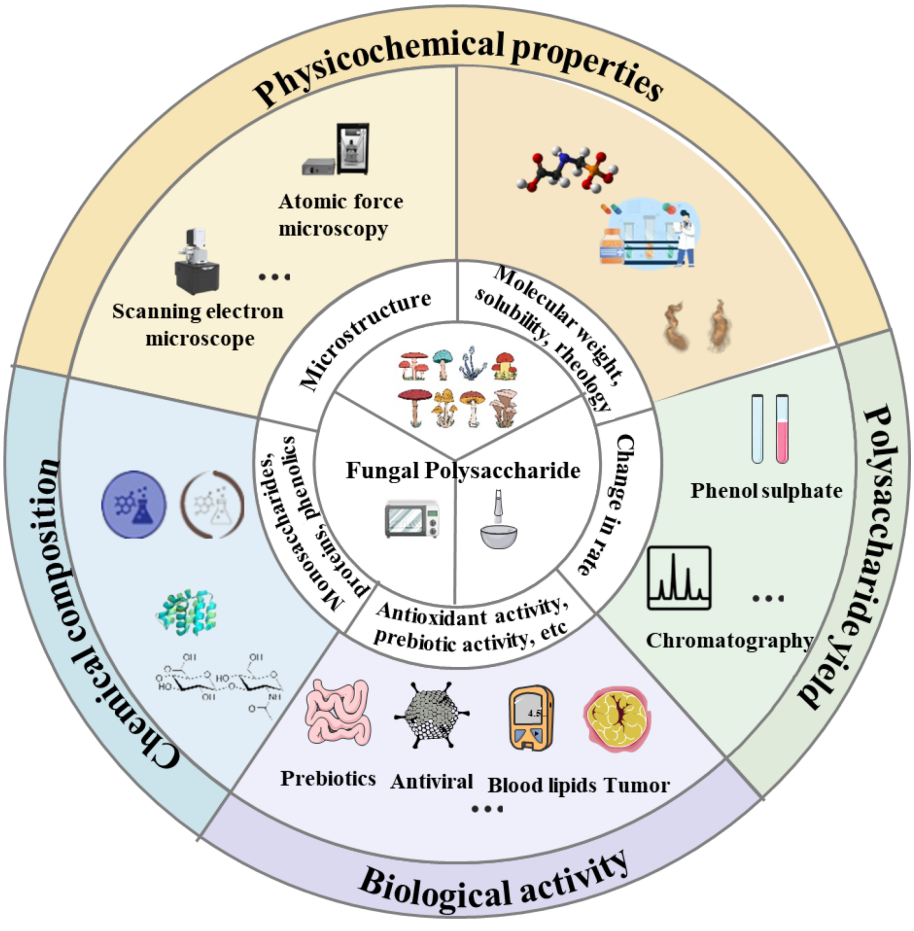

Figure 1 Effect of different drying and grinding methods on the multifaceted aspects of fungal polysaccharides.

produce desired products. With increasing demand, mixed drying methods are being considered for their energy efficiency, and the correct combination order is key to their effectiveness[14].

2.2 Grinding methods

Grinding is fundamental in extracting and processing fungal polysaccharides. The right grinding technique enhances the dissolution rate of functional components in edible mushrooms, thereby boosting their health benefits. Grinding also alters the physical properties and functional activity of the dietary fiber in mushrooms.

In dry grinding, grinding improves the texture of the material, achieving ultrafine powders through methods such as impact, abrasion, or cutting. Main techniques include: Air flow pulverization. This method uses high-speed air flow to pulverize materials, making it suitable for heat-sensitive materials. Ball grinding pulverization is a low-cost, green technology that reduces particle size to nanoscale. It provides mechanical action to alter the powder and reduce its relative crystallinity, making it more useful; In wet grinding, shear forces created by collisions between grinding media, chamber walls, and the material itself grind solid particles suspended in the liquid down to the nanometer level; Planetary ball grinding involves high-energy collisions of grinding media in a rotating platform, ideal for achieving fine particle sizes; High pressure homogenization uses high pressure to force materials through a narrow gap, breaking them into smaller particles, which is effective for creating uniform, fine dispersions; Micro-fluidics uses small channels to process materials at the micro-scale, which can produce highly uniform particles; Ultrasonic homogenization uses ultrasonic waves to create cavitation bubbles that break particles apart, making it suitable for nano-sized particles; Colloidal grinding involves grinding materials into a colloid-like consistency, which can be useful for certain applications where a smooth texture is desired[15-18].

Pre-treatment of raw materials, such as grinding, is a crucial preparatory step for enhancing the extraction rate of polysaccharides. Ultrafine grinding can break down cell walls, thereby accelerating the dissolution of polysaccharides[19]. Different grinding methods and conditions influence the chemical composition and physicochemical properties of fungal polysaccharides, affecting their composition, structure, morphology, thermal, and rheological properties.

3 Effects of drying and grinding techniques on fungal polysaccharide yield

Fungal polysaccharides yield can be increased by optimizing the influencing factors. Different processing methods have varying impacts on yield. For example, although FD is widely used in the food and pharmaceutical industries and is considered a superior method because the low temperatures applied in this process allow for the highest retention of bioactive compounds comparable to those in the raw materials. Ultra-fine grinding technology is a fast method that can be conducted at low temperatures, producing fine, uniform particles, conserving raw materials, and increasing yield. The improved polysaccharide yields from these methods highlight the necessity and feasibility of grinding and drying treatments[20,21].

3.1 Drying technologies

Polysaccharide yield can vary significantly due to differences in drying and extraction techniques[22]. This indicates that HD and VFD effectively retain polysaccharides. In *Pleurotus ostreatus*, FD increased polysaccharide content by 56% compared to DAD[23]. FD preserves bioactive proteins and polysaccharides, while DAD enhances nutritional value through self-hydrolysis. For *Cordyceps militaris*, ID showed the highest extraction rate of 3.61%, followed by FD at 2.60% and HD at 2.19%[24]. In *Pleurotus. eryngii*, polysaccharide yields were highest with FD ((7.31 ± 0.15)%), followed by boiling treatment and OD[25]. The lower yield in boiling-treated (BT) likely results from polysaccharide loss in hot water. Additionally, *C. sinensis* processed with FD showed increased yields with additives and a lowered initial pH value[26].

Drying techniques significantly impact the yield of fungal polysaccharides. High temperatures can cause polysaccharide degradation, reducing yield and quality. For instance, thermal drying is cost-effective and fast but may lead to degradation. FD, though more expensive, preserves the natural structure and function of polysaccharides, resulting in higher yields. Choosing the right drying method requires balancing efficiency and polysaccharide yield.

3.2 Grinding techniques

Plant polysaccharides are primarily located within the cell walls, grinding fungal materials to obtain a uniform powder, requiring proper pre-treatment to dissolve effectively. The method and degree of grinding significantly impact polysaccharide yield. Cell wall polysaccharides were extracted from *Sparassis latifolia* fruiting bodies using acid-base and ultrafine grinding-assisted methods. The chemical properties and *in vitro* immunological activities of these polysaccharides were analyzed and compared. Ultrafine grinding-assisted extraction produced the highest polysaccharide yield (20.80%), but with a lower β-glucan content (19.35%) compared to alkaline extraction.grindgrind[27]. Similarly, *Phellinus igniarius* fruiting bodies showed a significant increase in polysaccharide yield with ultrafine grinding compared to regular grinding[28]. In *T. fuciformis*, a 20-min ultrafine grinding process resulted in the highest yield of 48.0%[29]. The dissolution rates of polysaccharides from different treated *Lentinula edodes* stipe powders were also examined, with ultrafine powder achieving a rate of 1.37% in just 1 min surpassing the rates of 40-mesh at 0.14% and coarse powders at 0.10%[30]. In the case of *Ganoderma lucidum* spore powder, pre-treatment with physical freezing followed by ultrafine grinding led to an increase in polysaccharide yield from 0.83% to 1.55%[21]. This suggests that breaking the cell walls enhances polysaccharide dissolution and utilization. A positive correlation was found between polysaccharide yield and the degree of cell wall disruption. These research results indicate that grinding leads to the complete disruption of cells, which is essential for the effective release of intracellular polysaccharides from edible fungi. The polysaccharide yield is directly influenced by the degree of grinding.

4 Effects of drying and grinding techniques on the microstructural characteristics of fungal polysaccharides

Fungal polysaccharides, due to their large molecular weight and complex structures, lack a well-defined crystalline form, complicating the study of their secondary and higher-order structures. Techniques like atomic force microscopy (AFM), scanning electron microscopy (SEM), and transmission electron microscopy are crucial. AFM effectively analyzes the intricate structures of polysaccharides, surpassing the limitations of traditional light and electron microscopy[21]. Additionally, SEM provides valuable insights into the three-dimensional distribution of polysaccharides within the cell wall, revealing significant structural differences after various drying and grinding methods.

Exopolysaccharides (EPS) extracted from *Lactobacillus curvatus* were FD. SEM results revealed a flaky structure, while AFM showed a peak-like morphology[31]. For *Lactobacillus fermentum*, EPS purified after FD exhibited an uneven surface with round holes at 2,000× magnification under FE-SEM. At 5,000×, the surface appeared as a hollow porous structure with pits, indicating high porosity, which exposed many free hydroxyl groups, enhancing hydration and water retention capacity[32]. In *C. militaris* fruiting body polysaccharides, SEM analysis after HD, ID, and VFD showed that the FD treated samples had consistent particle sizes, neat distribution, and clear structure, indicating maintained structural integrity. In contrast, ID-treated samples displayed rough surfaces with uneven particle sizes and significant structural collapse, likely due to increased hardness from the ID treatment[9]. For *Auricularia auricula* polysaccharides analyzed at 5,000× magnification, samples from HD, ID, FD, and MD exhibited rough surfaces with granular structures dispersed in irregular debris. This dense granulation likely resulted from reduced protein content after deproteinization, where decreased protein repulsion led to tighter polysaccharide aggregation[33]. The morphological properties of polysaccharides from spent *Lentinus edodes* substrate were analyzed after FD, VD, and SD. VD-treated SLSP appeared as irregularly distributed smooth rocks, while SD-treated polysaccharides showed a uniform particle size distribution. At 1,000× magnification, FD-treated SLSP exhibited numerous pores and a rough surface[34].

When fungal raw materials were grinded, varying particle sizes and morphologies were observed. Pre-treatment of *A. auricula* resulted in coarse, fine, airflow, and ball-milled powders. Under electron microscopy, the microstructures transitioned from uneven amorphous and rod-like shapes to more uniform spherical structures. X-ray diffraction analysis revealed that coarse and ball-milled powders had minimal crystalline regions, whereas fine and airflow powders displayed peaks, indicating intermittent crystalline regions and validating the small size effect[35].

The rate and extent of moisture evaporation during drying affect polysaccharide shrinkage and pore formation, impacting their microstructure. For example, thermal drying may cause polysaccharides to compress and aggregate, while freeze-drying at low temperatures can preserve the natural microstructure and prevent heat degradation and shrinkage. After grinding, ultrafine powders usually have smoother surfaces, while coarse powders show more edges and rough surfaces. Additionally, grinding can alter the crystalline structure of polysaccharides, transforming them from an ordered crystalline state to an amorphous form. The choice of grinding and drying methods significantly impacts the structure and function of fungal polysaccharides. Selecting appropriate grinding and drying techniques is crucial for optimizing their functionality.

5 Effects of drying and grinding techniques on the chemical composition of fungal polysaccharides

Fungal polysaccharides are determined by their

physicochemical properties to dictate their physiological functions. Understanding these functions requires detailed analysis of their molecular structure. Polysaccharides are composed of complex, long chains of various monosaccharides, which can form straight or branched configurations, with potential modifications to the sugar residues. Their high molecular weight and intricate structures present challenges for accurate analysis. Key aspects of their chemical composition include chain size and state, degree of branching, interactions between main and side chains, molecular weight, the composition and ratio of monosaccharides and uronic acids, bonding patterns of sugar groups, and the conformation of the anomeric carbon[36].

Different grinding and drying methods can significantly affect the physicochemical properties of polysaccharides. These processes may alter molecular weight, solubility, and structural integrity, impacting their functionality and bioactivity.

5.1 Monosaccharides

Numerous experimental results show that different drying methods have no significant effect on the composition of monosaccharides, but do affect their ratio. Different biological activities can be observed with different monosaccharide contents. Experimental results indicate that different drying methods do not significantly affect the monosaccharide composition but alter their ratios, impacting biological activity. Oxygen (Oxy) and temperature may cause conformational changes in monosaccharides, affecting their content. Common monosaccharides in mushrooms include mannose (Man), glucose (Glc), and galactose (Gal)[37, 38].

In Cs-4 fungus mycelium, extracellular and intracellular polysaccharides were extracted via ethanol precipitation and FD. These polysaccharides were composed of fucose (Fuc), arabinose (Ara), Gal, Glc, xylose (Xly), Man, and ribose (Rib), with Ara, Gal, Glc, and Man being the predominant being predominant. These monosaccharides are also present in other *Cordyceps* polysaccharides[39, 40]. Ion chromatography analysis of *C. militaris* fruiting body polysaccharides showed that under HD, ID, and FD treatments, Glu content was highest in FD, while Man and Gal were lowest[24]. In another study, *T. fuciformis* polysaccharides underwent MVD, ultrasound-assisted combined with MVD, and USMVD[41]. The primary monosaccharides were Fuc, Ara, Rha, Glu, Man, and Xyl, with Fuc, Man, and Xyl being most prevalent. Compared to HD, MVD, USMVD, and US + MVD slightly reduced monosaccharide content, possibly due to hydroxyl oxidation and hydrogen bond breakage in hot air or oxygen-rich environments. The bioactivity of fungal polysaccharides is closely related to their monosaccharide composition and glycosidic bond types[42]. For *A. auricula* polysaccharides, the molar ratios of monosaccharides under different treatments were: FD (13.73:0.98:1:2.87:8.32), HD (12.00:1.80:1:2.53:7.01), and ID (12.34:2.04:2.01:2.53:7.01)[33]. A heteropolysaccharide was obtained from the substrate of Morchella esculenta by the FD and its monosaccharide composition was analyzed by HPLC reversed-phase analysis, which showed that Morchella esculenta polysaccharide was a heteropolysaccharide composed of Man, Glu and Gal (1.00:7.84:1.24)[43]. Although the polysaccharide compositions from different drying methods were similar, their contents varied.

Using ordinary and ultrafine grinding, polysaccharides were extracted from *G. lucidum*, resulting in powders of varying fineness. Polysaccharides precipitated with 30% ethanol contained only Glc, while those with 70% ethanol included Gal, Glc, and minor amounts of Fuc, Man, and Glc. Increased grinding fineness did not significantly affect the monosaccharide composition of the 70% ethanol fraction[44]. Using ultrafine grinding, *G. lucidum* were further analyzed via high performance liquid chromatography (HPLC) and Fourier transform infrared spectroscopy (FT-IR). Ethanol precipitation at 40%, 60%, and 80% yielded composed of Man, Rib, Glc, Gal, and Fuc, with Glc being most abundant. The FT-IR results showed that the monosaccharides were in the β-pyranose form[45]. Different grinding methods did not significantly change the composition of *Ganoderma* polysaccharides but may affect their content.

5.2 Protein

The reduction in protein content following the drying of the polysaccharide solution is expected, as some proteins may denature. Besides temperature effects, changes in the solubility and pH of the extract can also alter the secondary and tertiary structures of proteins or disrupt linker peptides[46].

Polysaccharides from shiitake mushrooms were analyzed using various drying methods (HD, ID, VFD, PVD, RHD, IHD). Fresh shiitake and VFD polysaccharides had higher protein content (8.89% and 7.56%) compared to those from heat treatments respectively, likely due to protein denaturation and hydrophobic exposure reducing protein levels[47]. In *Agaricu blazei*, drying significantly decreased EPS protein content, with less reduction in FD and VD compared to SD, suggesting FD and VD are more effective for preserving proteins. Since β-*D*-glucan, a key anti-tumor compound, is protein-bound, protein loss could reduce its efficacy[46]. For *P. eryngii*, FD yielded higher protein content ((2.05 ± 0.12)%) than ((0.96 ± 0.15)%) and BT ((0.78 ± 0.17)%). In *P. ostreatus*, VD, ID, and HD showed weaker protein absorption at 280 nm, indicating minimal protein presence. FD effectively retained nutrients, while Maillard reactions in OD and BT may account for lower protein levels[23]. *Agaricus bisporus* powder obtained through grinding, ultrafine grinding and ultraviolet radiation-B (UV-B) treatment improved brightness, protein, and vitamin D_2 content without affecting ash content[48].

These show that FD and ultrafine grinding effectively preserve higher protein content and reduce nutrient loss, maintaining better bioactivity. These methods are more beneficial than traditional heat treatments in preserving the structural integrity and functional properties of polysaccharides.

5.3 Phenolic resins

Fungal polysaccharides' chemical composition has a significant impact on their physicochemical properties and processing performance. Ultrasonic cavitation in VFD can break down polysaccharides, reducing both polysaccharide and glyoxylic acid content. HD, due to high temperatures and prolonged drying times, leads to color deterioration, nutrient degradation, and lower uronic acid levels[23].

For *A. auricula* polysaccharides, different drying methods were used, with FD yielding the highest uronic acid content (33.53%) and the lowest molecular weight. Absorption peaks at 2,930, 1,620, and 1,420 cm^{-1} indicated the presence of sugars and uronic acids[33]. In shiitake mushrooms, although fresh samples had significantly higher uronic acid content compared to dried ones, IHD resulted in the highest uronic acid content among the dried samples (13.69%)[47]. In *C. militaris* polysaccharides, VFD treatment led to higher uronic acid content (26.55%) compared to HD (21.73%) and ID (20.55%)[23]. For *T. fuciformis*

polysaccharides, the US + MVD method significantly increased uronic acid content (6.75%). This may be due to the high acoustic energy density reducing drying time and oxygen exposure, thereby inhibiting uronic acid oxidation[41]. Additionally, airflow ultrafine grinding of shiitake mushroom powder resulted in the highest free phenol content ((0.445,7 ± 0.007,6)%), while conventional grinding showed the highest bound phenol content ((0.027,4 ± 0.001,8)%)[49].

Different drying and grinding methods can influence the chemical composition and nutritional properties of fungal polysaccharides. Ultrasonic VFD and IHD may help maintain higher uronic acid levels by reducing oxidation and degradation. Airflow ultrafine grinding can increase free phenol content, helping to preserve bioactive compounds and overall nutritional value.

6 Effects of drying and grinding techniques on the physicochemical properties of fungal polysaccharides

6.1 Molecular weight

Fungal polysaccharides are closely related to their molecular weight, which significantly influences their biological activity. These factors significantly influence the physical and chemical properties of polymers. The drying process greatly affects the molecular weight and, consequently, the biological activity of polysaccharides.

For example, an exopolysaccharide from *L. fermentum* S1, the molecular weight of the polysaccharides obtained via FD (7.19×10^5 Da), mainly composed of Man, Rha, Glu, and Gal[32]. The molecular weights of four types of *A. auricula* polysaccharides obtained through different drying methods were measured using HPLC by a study, revealing significant differences. different drying methods resulted in varied molecular weights: FD (4.07×10^5 Da), HD (1.03×10^6 and 1.72×10^5 Da), ID (1.00×10^6 and 3.90×10^5 Da), and MD (1.56×10^6 and 3.27×10^5 Da)[33]. For *T. fuciformis* polysaccharides, HD and US + MVD produced higher molecular weights (3.60×10^5 Da) than fresh samples (2.82×10^5 Da), likely due to rapid water removal and polysaccharide aggregation. The results indicated that with the rapid removal of bound water, especially under hot air conditions, polysaccharide chains tended to aggregate, resulting in increased molecular weight[39]. The changes in polysaccharides of *T. fuciformis* after drying at 18 °C with cold air, 50 °C HD, and FD were compared. CAD *Tremella* had the highest molecular weight (2.41×10^7 Da) and moisture content (13.05%)[50]. By employing ultrafine grinding technology in the deep processing of edible fungi, the dissolution rate of their functional components can be significantly improved, thereby amplifying their bioactive effects within the human body, low-temperature superfine grinding, in particular, better preserves the structural integrity of spore powder compared to room-temperature ball milling, enhancing the release of polysaccharides and triterpenoids during digestion[51,52]. For *C. militaris* polysaccharides, High performance gel permeation chromatography (HPGPC) analysis showed similar molecular weight ranges across drying methods. However, the molecular weights of peak 2 in FD (2.81×10^4 Da) and HD (2.75×10^4 Da) were higher than in ID (2.65×10^4 Da), with the proportion of peak 2 in FD significantly lower (26.834%) compared to HD and ID[21].

Different drying and grinding methods significantly affect the molecular weight and biological activity of fungal polysaccharides. FD typically preserves lower molecular weights, while HD and ultrasound-assisted drying can increase molecular weight. Ultrafine grinding improves extraction yields but has limited impact on the solubility of high-molecular-weight polysaccharides. Low-temperature ultrafine grinding better preserves the structural integrity of spore powder and enhances the release of polysaccharides and triterpenoids. Selecting the appropriate drying and grinding methods is crucial for optimizing the properties and functions of polysaccharides.

6.2 Solubility and dissolution

Three different drying methods for soluble EPS were studied. All methods significantly increased the reducing sugar content, primarily due to enhanced solubility of low molecular weight polysaccharides. As molecular weight and intermolecular binding increase, solubility decreases. Hydrogen bonding facilitates interactions between polysaccharide chains and water, making them more easily hydrolyzed[46]. For *C. sinensis* samples processed by HD, ID, and VD showed similar uniformity and solubility in water. Additionally, HAD *P. ostreatus* had three times the water-soluble protein content of fresh samples, likely due to heat treatment degrading proteins stabilized by weak bonds, thus increasing solubility and diffusion[24]. In *G. lucidum* cultivated on mushroom grass, superfine powder showed 24% and 15.2% higher dissolution amounts of polysaccharides and triterpenes compared to fine powder. Dissolution rates were also faster, with cumulative amounts reaching over 95% and 90% at 90 min, while fine powder reached only about 70%[53]. Ultrafine grinding technology not only maximizes the preservation of the functional components and their efficacy in raw materials, but also significantly enhances the dissolution and bioavailability of these components, thereby optimizing their functional performance[51]. In another study, *A. bisporus* was dried using HD, HPD, and VFD, followed by coarse (60 mesh) and superfine grinding (300 mesh). VFD samples showed the highest bulk density, hydration capacity, and dissolution of crude polysaccharides, soluble proteins, and total triterpenes[54]. Additionally, polysaccharides from *Lentinula edodes* superfine powder and high-pressure processing were examined. Soluble dietary fiber contents were 9.63% and 7.00%, with protein solubility at 2.51% and 2.25%, and polysaccharide solubility at 4.92% and 3.56%, respectively. Protein and polysaccharide solubility slightly increased with soaking time from 20 min to 100 min[55].

Ultrafine grinding enhances the solubility and dissolution rates of polysaccharides and triterpenes, improving bioavailability. Samples processed with VFD showed the highest hydration capacity and solubility. Heat treatment increased solubility by degrading proteins. Overall, different drying and grinding methods significantly impact the solubility and dissolution rates of fungal polysaccharides.

6.3 Rheological properties

The gelation of fungal polysaccharides is vital for enhancing food texture and sensory properties, allowing them to function as thickeners, stabilizers, gelling agents, and adhesives in various food products. Their rheological properties significantly impact extraction processes, food design, sensory evaluation, product development, and shelf life[56,57].

Studies have shown that the apparent viscosity and stress variations of Tremella polysaccharide solutions differ based on the

drying methods used. Polysaccharides with lower molecular weight exhibit reduced flexibility and pseudoplasticity. When subjected to the same acoustic energy, air ultrasound-treated solutions showed higher viscosity compared to water bath ultrasound treatments. This increase is likely due to enhanced molecular interactions facilitated by ultrasound[41]. Additionally, different pulverization methods significantly altered the rheological properties of edible fungi. In *Inonotus obliquus* powder, ball grinding and micronization initially decreased particle size, reaching a minimum after 2 h, and then increased with further grinding[58] The particle size distribution exhibited a bimodal pattern, with the morphology changing from smooth strips to rough lumps. Bulk and tapped densities initially increased and then decreased with prolonged grinding. Similarly, airflow ultrafine pulverization of shiitake mushroom stem powder reduced the average particle size to 3.21 μm, increasing specific surface area and improving flowability, bulk density, tapped density, water-holding capacity, and swelling capacity[30].

In another study, insoluble polysaccharide nanoparticles from enoki mushrooms were prepared using hot water, cold alkali, and hot alkali pretreatments. The extracted polysaccharides were then combined with wet grinding and high-pressure homogenization treatment. The resulting nanoparticles demonstrated non-Newtonian shear-thinning behavior, with viscosity increasing in the order of hot water, cold alkali, and hot alkali. Kinetic rheological analysis showed differences in storage modulus (G') and loss modulus (G'') among the dispersions[59].

Different drying methods affect the molecular weight and structure of polysaccharides, impacting their viscosity and pseudoplasticity. VFD typically maintains higher rheological properties, while HD may reduce viscosity. Sonic drying enhances the apparent viscosity of polysaccharide solutions, outperforming water bath ultrasound. Ultrafine grinding reduces particle size and increases surface area, improving powder flowability and hydration, thus enhancing polysaccharide viscosity. Low-temperature ultrafine grinding better preserves structural integrity compared to room temperature ball grinding, further improving rheological performance.

Overall, suitable drying and grinding methods can optimize the rheological properties of fungal polysaccharides, enhancing their applications in the food industry.

7 Effects of drying and grinding techniques on the biological properties of fungal polysaccharides

Fungi, including their mycelium, fruiting bodies, sclerotia, and spores, are rich in beneficial components such as amino acids, vitamins, polysaccharides, alkaloids, and sterols, all advantageous to human health. Among these, fungal polysaccharides are vital bioactive compounds in medicinal fungi. Recent research, both domestic and international, has demonstrated that these polysaccharides significantly contribute to key biological processes as natural antioxidants and immunomodulators. The evaluation of polysaccharide activity, similar to other pharmaceuticals, occurs at the molecular, cellular, and animal levels. As complex natural substances, fungal polysaccharides exhibit a range of biological activities, including anti-tumor, antioxidant, immunomodulatory, anti-aging, anti-fatigue, lipid-lowering, glucose-lowering, and anticoagulation properties (Fig. 2)[60-62].

7.1 Antioxidant activities

Preventing lipid peroxide accumulation, a key factor in hyperlipidemia pathogenesis, can be achieved through antioxidant properties. Research indicates that the antioxidant activity of polysaccharides is influenced by factors such as monosaccharide composition, uronic acid content, and molecular weight[63]. 1, 1-Diphenyl-2-picrylhydrazyl (DPPH), a stable free radical, is widely used to measure the free radical scavenging abilities of various compounds.

7.1.1 Drying techniques

Polysaccharides were extracted from *A. blazei Murrill* using FD, VD, and air drying methods. The three types of *A. blazei* Murrill polysaccharides exhibited different physicochemical and antioxidant properties. Compared to VD and air drying, the

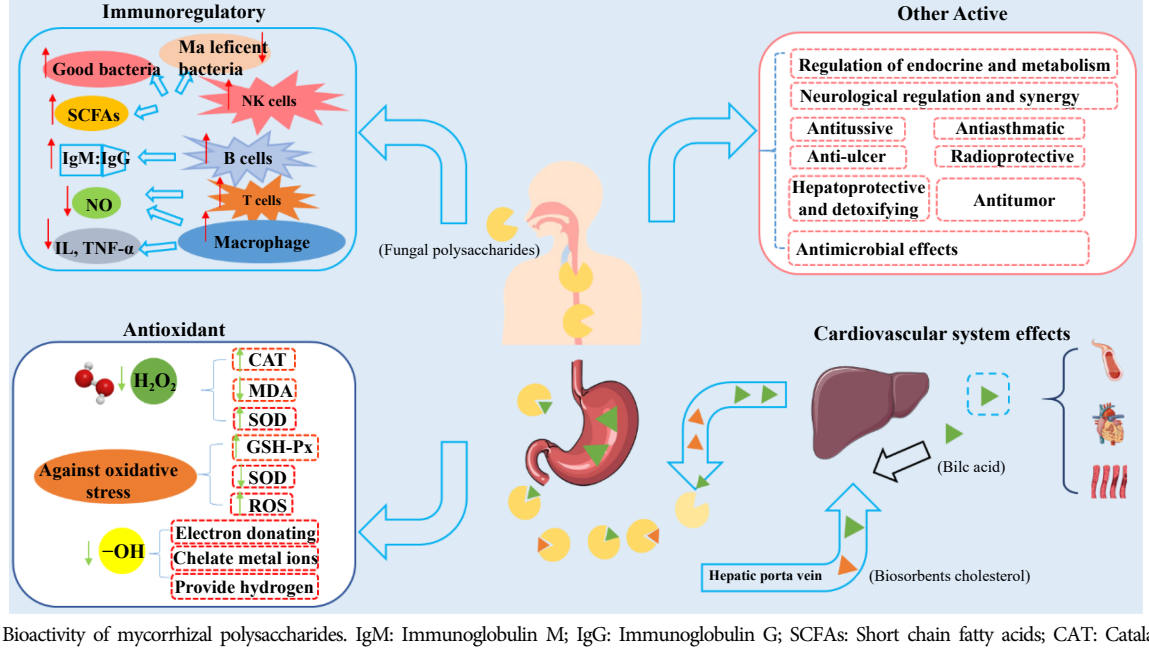

Figure 2 Bioactivity of mycorrhizal polysaccharides. IgM: Immunoglobulin M; IgG: Immunoglobulin G; SCFAs: Short chain fatty acids; CAT: Catalase; MDA: MAlondialdehyde; SOD: Superoxide dismutase; GSH-Px: Glutathione peroxidase; ROS: Reactive oxygen species.

polysaccharides obtained through FD showed higher hydroxyl radical, DPPH radical, and it radical scavenging abilities, as well as Fe^{2+} chelation antioxidant activity[64]. This is likely because FD prevents the degradation of heat-sensitive polysaccharides and the oxidation of active substances. EPs from *L. curvatus* demonstrated antioxidant capacities of 84.50% for DPPH and 92.53% for ABTS at a concentration of 5.0 mg/mL[31]. Crude polysaccharides from fresh shiitake mushrooms, dried using FD and HD, enhanced immunity by inducing the secretion of nitrogen monoxide (NO), tumor necrosis factor-α (TNF-α), and interleukin-6 (IL-6). The immunomodulatory activity of LEP increased through HD[65]. Polysaccharides from *P. eryngii*, treated with VFD, HD, and ID, showed an increasing DPPH radical scavenging rate with concentration. The ID method consistently resulted in a higher scavenging rate than VFD and HD, reaching 70.14%, compared to 68.78% and 63.81%, respectively[23]. These results indicate that the DPPH radical scavenging ability of ID was superior to that of HD and VFD, demonstrating better antioxidant capacity.

7.1.2 *Grinding techniques*

In terms of grinding, the highest yield of fungal polysaccharides (48.0%) was achieved when dried white fungus powder was ultra finely ground for 20 min and extracted using a combined ultrasonic and microwave method. The antioxidant properties of polysaccharides prepared with varying ultrafine grinding times were studied. Polysaccharides extracted after 20 min of ultrafine grinding exhibited the highest OH^- radical scavenging rate, reaching 29.4%. Those extracted after 8 min had the highest DPPH radical scavenging rate at 79.7%, while extraction after 15 min showed the highest O^{2-} radical scavenging rate at 92.5%[29].

A positive correlation was noted between ultrafine grinding time and the extraction rate of white fungus polysaccharides, though no positive correlation was found with antioxidant activity against OH^-, DPPH, and O^{2-} radicals. Further studies on *A. bisporus* powder indicated that ultrafine powder, compared to regular powder, had a smaller particle size, greater bulk density, better water solubility, higher release of nutritional and functional components, and stronger antioxidant activity[54]. These findings suggest that ultrafine grinding is a commonly used method, and grinding time is associated with antioxidant capacity.

7.2 Probiotic activity

Fungal polysaccharides are often considered "biological response regulators" due to their various biological activities, including a growing interest in their prebiotic potential through gut microbiota regulation. Notably, *D*-glucan, a dietary fiber and bioactive natural polysaccharide, is valued for its low production cost, high tolerance, and diverse structural properties. Additionally, prebiotic effects are linked to α-glucan and chitin, with chitin also possessing antibacterial and wound-healing properties[66,67].

Polysaccharides were prepared by pulverizing the hyphae of *P. ostreatus* using VFD and sieving through an 80-mesh screen. Intake of these polysaccharides increased the abundance of short-chain fatty acid-producing bacteria in mice with alcohol-induced liver injury, maintaining gut microbiota balance. This process effectively protected intestinal villi and tight junctions via the "gut-liver axis," preserving intestinal barrier integrity[68]. *C. sinensis* polysaccharides, after protein removal and dialysis, followed by FD, restored short-chain fatty acid levels reduced by cyclophosphamide treatment. α- and β-diversity analyses showed increased probiotic abundance, reduced pathogenic bacteria, and improved overall gut microbiota structure, demonstrating the prebiotic potential of *Cordyceps* polysaccharides[69]. To enhance the prebiotic value of polysaccharides from *Grifola frondosa*, a decolorization method was studied to examine their physicochemical properties and prebiotic potential[70]. These findings suggest that optimizing the preparation and processing of fungal polysaccharides can significantly enhance their prebiotic effects.

7.3 Other biological properties

Fungal polysaccharides are renowned for their diverse bioactivities, including anti-radiation, anticoagulant, antithrombotic, and antiviral effects. Recent studies highlight their potential as prebiotics that regulate gut microbiota and as therapies for diabetes. Edible mushrooms contain beneficial compounds such as fibers, polysaccharides, phenols, and alkaloids, recognized for their anti-diabetic, antioxidant, and lipid-lowering properties. Among these, β-glucan—a complex, insoluble glucose polymer found in the cell walls of fungi, algae, and bacteria—has been shown to lower blood cholesterol levels and improve glucose absorption, contributing to wound healing. It also acts as an effective immunostimulant in humans and animals, aiding in the treatment of diabetes, hypercholesterolemia, infections, and cancer. Functional foods and supplements derived from mushrooms may delay the onset of chronic diseases and assist in managing type 2 diabetes by lowering blood glucose and alleviating symptoms[71,72].

Polysaccharides from *T. versicolor*, prepared via FD and extraction, resulted in two types, CVPn and CVPa. CVPn influenced macrophage phagocytosis, while CVPa significantly enhanced the activity of RAW264.7 cells, boosting immune defense mechanisms[73]. An α-glucan extracted from H. sinensis mycelia, obtained through VFD, significantly enhanced macrophage phagocytosis by activating the p38, JNK, and NF-κB pathways, increasing the production of NO, IL-1β, IL-6, and TNF-α, and promoting lymphocyte proliferation[74]. Polysaccharides from *A. auricula* were extracted from both crude and ultrafine powders using acid methods[75]. After ultrafine grinding, the molecular weight decreased, enhancing lipid-lowering effects. Extracellular polysaccharides from freeze-dried Cs-4 mycelium inhibited platelet activation and aggregation, reducing P-Selectin (CD62P) expression and integrin αIIb subunit (αIIbβ3) activation, potentially preventing thrombotic diseases[39]. In *A. auricula*, various powder forms were analyzed, with ultrafine powder showing significant reductions in triglycerides and increased high-density lipoprotein levels, indicating superior lipid-lowering effects[35]. In studies of *A. blazei* polysaccharides, β-*D*-glucan emerged as the primary anti-tumor compound, demonstrating significant inhibition of Ehrlich tumor cell proliferation[46].

These findings emphasize the need to further explore the impact of different drying and grinding techniques on the biological properties of fungal polysaccharides *in vivo*, enhancing our understanding of the relationship between their structure and efficacy.

8 Conclusion

Fungi, as a vital biological resource in China, play a significant role in scientific research and daily life. In recent years, research on fungal polysaccharides has garnered increasing attention. These polysaccharides possess a wide range of physiological functions,

including antioxidant, anti-tumor, antiviral, antibacterial, anti-inflammatory, immune regulation, blood sugar reduction, and lipid-lowering effects, indicating broad application prospects. However, the processes of drying and grinding are critical in the preparation of fungal polysaccharides, significantly impacting their yield, molecular weight, and biological activity. This paper reviews the effects of various grinding and drying methods on the physicochemical properties and biological activities of fungal polysaccharides.

FD is the preferred method for preparing fungal polysaccharides. Conducted under low-temperature and vacuum conditions, FD avoids the liquid phase transition of water, minimizing heat damage to the polysaccharide molecules. This process preserves the active components and complex structures of the polysaccharides, reducing thermal degradation and achieving high yields. Consequently, FD maintains the biological activity and functional components of fungal polysaccharides, unlike other drying methods such as HD and SD which, despite being cost-effective and suitable for large-scale production, operate at high temperatures that can partially degrade the polysaccharides and diminish their biological activity. HD removes water through the flow of heated air, while SD atomizes the polysaccharide solution into fine particles dried rapidly by hot air. Both methods can break polysaccharide molecular chains or alter their structure, thereby compromising their biological activity, particularly antioxidant activity, due to the degradation of phenolic and flavonoid compounds under high temperatures.

Grinding also significantly affects the properties of fungal polysaccharides. The primary purpose of grinding is to increase the surface area of the polysaccharides, facilitating solvent penetration into the cells. Smaller particles provide a larger contact area, promoting the dissolution and release of polysaccharides, thereby enhancing extraction efficiency. However, the mechanical force exerted during high-speed rotation and impact can break molecular chains and damage the structure, reducing molecular weight. The molecular weight of polysaccharides is crucial for their biological activity; higher molecular weight typically means better adhesion and biological activity. The anti-tumor and immune-regulating activities of polysaccharides depend on their specific molecular weight and structure, and excessive grinding can weaken these key characteristics. Therefore, it is essential to precisely control the grinding time and degree to maintain the optimal functional properties of polysaccharides. While ultrafine grinding can improve solubility, the grinding parameters must be tailored to the specific fungi to achieve maximum benefits and functionality.

In conclusion, selecting appropriate drying and grinding methods is vital for the quality and application of fungal polysaccharides. Optimizing these processes can significantly enhance extraction efficiency and functional properties. Continuous research and development of new technologies to improve the preparation and processing of fungal polysaccharides are essential. As biotechnology and engineering advance, the potential of fungal polysaccharides in disease prevention and treatment will be further explored, contributing to human health.

Conflicts of interest

The authors declare that there are no conflicts of interest in this work.

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