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Purification of Polysaccharides from By-products of Ginsenoside Extraction and Development of Functional Foods

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Abstract: *Ginseng, a perennial herb of the Araliaceae family, is widely used in the pharmaceutical and food industries due to its main active ingredient, ginsenosides. However, the extraction of ginsenosides generates a large quantity of by-products such as marc, which are often discarded, leading to resource wastage and environmental pressure. Studies have found that these by-products are rich in ginseng polysaccharides, which possess various biological activities such as immunomodulatory, antitumor, neuroprotective, and antioxidant effects, demonstrating high development value. This paper systematically reviews the extraction and purification processes of polysaccharides from ginsenoside extraction by-products, including crude extraction methods, refining and purification techniques, and structural identification methods, analyzes their main biological functional properties, and discusses the current status and prospects of their development and application in the field of functional foods, thereby providing a theoretical basis for the comprehensive utilization of ginseng resources and promoting the development of the industry for high-value transformation of ginseng by-products.*

Keywords: *Ginsenosides, By-products, Ginseng polysaccharides, Purification process, Functional foods*

1. Introduction

1.1. Research Background

Ginseng (Panax ginseng C. A. Meyer) is a precious traditional Chinese medicinal herb with a history of thousands of years of use in East Asia. Its medicinal value and health benefits are globally recognized. Ginsenosides, as the core active components of ginseng, belong to the class of triterpenoid saponins, formed by the condensation of sugars and aglycones[1]. They possess various pharmacological effects such as antitumor, anti-inflammatory, immunomodulatory, and cardiovascular protective actions and are widely used in pharmaceuticals, health products, and cosmetics[2]. Currently, the industry primarily uses ethanol extraction processes to obtain ginsenosides, which generates a significant amount of post-ethanol-extraction marc as by-products. These by-products account for over 70% of the total mass of the raw ginseng material and are mostly directly discarded or incinerated, causing not only severe resource wastage but also environmental issues.

In recent years, with the deepening of resource recycling concepts and advances in natural product research, high-value utilization of these by-products has become a research hotspot. Studies indicate they are rich in ginseng polysaccharides (GP)—an acidic heteropolysaccharide composed of uronic acids and neutral sugars (56.9% acidic sugars, 28.3% neutral sugars, protein content <0.1%). GP exhibits unique biological activities (adjuvant cancer therapy, alleviating radiotherapy/chemotherapy adverse reactions, neuroprotection, antioxidation) with wide sources and high safety, making it suitable for functional food development[3]. Therefore, this research is of great practical significance for full-chain utilization of ginseng resources, industrial added value enhancement, and environmental pressure reduction.

1.2. Current Research Status

Currently, domestic and international research on ginseng polysaccharides primarily focuses on

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fresh ginseng and ginseng roots/rhizomes. Research on polysaccharides from ginsenoside extraction by-products is relatively recent. Regarding purification processes, various techniques such as alcohol precipitation, enzymatic hydrolysis, resin adsorption, and ultrafiltration have been developed. Among these, composite purification processes have become mainstream due to their effectiveness and high purity. For example, one study used ginseng post-ethanol-extraction marc as raw material and successfully prepared high-purity ginseng acidic polysaccharides through a combined process of water extraction, alcohol precipitation, enzymatic hydrolysis, resin adsorption, and ultrafiltration[4]. In terms of biological activity, modern pharmacological studies have confirmed that ginseng polysaccharides can not only serve as adjuvant drugs for tumor therapy to reduce adverse reactions from radiotherapy and chemotherapy but also exert neuroprotective, antioxidant, and blood glucose-regulating effects by activating specific signaling pathways. Regarding functional food development, current product forms are relatively limited, mainly concentrated in health products such as polysaccharide oral liquids and capsules. Their application in conventional foods is still in the exploratory stage[5].

2. Extraction and Purification Processes of Polysaccharides from Ginsenoside Extraction By-products

The extraction and purification of polysaccharides from ginsenoside extraction by-products (mainly post-ethanol-extraction marc) are prerequisites for their high-value utilization, involving steps such as crude extraction, refining, purification, and structural identification. The crude extraction stage aims to separate polysaccharides from the marc to obtain crude polysaccharides. The refining and purification stage removes impurities such as proteins, pigments, and inorganic salts to improve polysaccharide purity. Structural identification provides a theoretical basis for subsequent functional research and product development.

2.1. Extraction Methods for Crude Polysaccharides

The extraction of crude polysaccharides is based on water extraction, combined with auxiliary techniques such as enzymatic hydrolysis, ultrasound, and microwave, which can effectively improve extraction efficiency while reducing extraction time and solvent consumption.

2.1.1. Water Extraction Method

Water extraction leverages the high solubility of polysaccharides in hot water to rupture cell walls and release target compounds. Using ginseng post-ethanol marc, the basic procedure includes crushing, reflux extraction, filtration, supernatant concentration, alcohol precipitation, and drying to obtain crude polysaccharides. Key factors—extraction temperature (80-100°C), liquid-to-solid ratio (15-25:1 mL/g), time (1-2 h), and repeated cycles (2-3 times)—collectively determine extraction efficiency. This method is simple, low-cost, eco-friendly, and suitable for industrial-scale production.

2.1.2. Enzyme-Assisted Extraction Method

Enzyme-assisted extraction enhances polysaccharide yield by adding enzymes such as cellulase, pectinase, and amylase during water extraction. These enzymes break down cell wall components like cellulose and hemicellulose, facilitating polysaccharide release. For example, using 0.19%-0.31% medium-temperature amylase at 65°C for 22-37 minutes in ginseng marc extraction can increase polysaccharide yield by 10%-15% while removing starch impurities, thus improving purity and simplifying subsequent purification. This method operates under mild conditions, consumes less energy, and preserves polysaccharide integrity, making it a preferred approach for crude polysaccharide extraction.

2.2. Refining and Purification Techniques for Polysaccharides

Crude polysaccharides contain numerous impurities such as proteins, pigments, inorganic salts, and starch, requiring refinement and purification techniques for removal to obtain high-purity polysaccharides. Common purification techniques include alcohol precipitation, decolorization, resin adsorption, and ultrafiltration, often used in combination in practice.

2.2.1. Alcohol Precipitation Method

Alcohol precipitation utilizes the low solubility of polysaccharides in high-concentration ethanol (typically 45%-75%) to separate them from soluble impurities like proteins and inorganic salts. This

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simple, cost-effective method is a fundamental purification step. The standard process involves concentrating the crude extract, slowly adding ethanol to the target concentration, refrigerating at 4°C overnight, centrifuging, washing the precipitate with 60% ethanol, and finally removing the solvent. Precipitation temperature, ethanol addition rate, and standing time are critical for purity and yield, with overnight refrigeration proving highly effective.

2.2.2. Decolorization Methods

Decolorization removes pigments such as flavonoids and polyphenols from crude polysaccharide extracts to improve both appearance and bioactivity. Common methods include activated carbon adsorption, ion-exchange resin, and hydrogen peroxide treatment. Large-pore polysaccharide-specific activated carbon is widely used due to its effective decolorization, simple operation, and absence of secondary pollution. Optimized conditions involve adding 0.75%-1.25% activated carbon at 60-70 °C for 30-50 minutes, achieving pigment removal while keeping polysaccharide loss below 10%. The ion-exchange resin method provides stable decolorization and can concurrently remove some proteins and inorganic salts, but its higher cost makes it more suitable for producing high-purity polysaccharides.

2.2.3. Resin Adsorption Method

The resin adsorption method, typically using anion exchange resins such as D900, separates acidic polysaccharides via ion exchange with their carboxyl groups. The process involves loading a polysaccharide solution onto the column, washing with distilled water to remove neutral impurities, eluting with sodium chloride solution, and then concentrating and precipitating the eluate to obtain refined acidic polysaccharides. Key purification parameters include a column diameter-to-height ratio of 1:10-1:20, sample loading of 5%–10% of resin volume, water elution of 3-5 column volumes, elution with 0.3 mol/L NaCl (4–6 column volumes) at 1.5-2.5 BV/h, achieving over 85% purity for ginseng acidic polysaccharides.

2.2.4. Ultrafiltration Method

The ultrafiltration method utilizes the sieving effect of ultrafiltration membranes to separate and purify polysaccharides based on molecular weight, simultaneously removing inorganic salts, small-molecule impurities, and some proteins from the solution. This method offers advantages such as mild operation, no chemical pollution, and retention of polysaccharide biological activity, often used as a desalting and refinement step after resin adsorption. Process parameters are: ultrafiltration membrane molecular weight cut-off 0.75-1.25 kDa, operating pressure inlet 1.88-3.12 bar / reflux outlet 1.35-2.35 bar, peristaltic pump speed 7.5-12.5 rpm, using ultrapure water as the elution solvent until the effluent shows no chloride ions (no turbidity with silver nitrate solution detection). The resulting polysaccharide solution after ultrafiltration is concentrated, alcohol-precipitated, and dried to obtain high-purity polysaccharides with purity greater than 90%.

3. Biological Functional Characteristics of Ginseng Polysaccharides

As a natural active polysaccharide, ginseng polysaccharides possess various pharmacological effects and health functions, with low toxicity and high safety, providing a solid theoretical foundation for their development in functional foods. In recent years, domestic and international researchers have conducted in-depth studies on the biological functions of ginseng polysaccharides, with main functions as follows.

3.1. Immunomodulatory Function

Immunomodulation is one of the core functions of ginseng polysaccharides. They can activate immune cells such as macrophages, T lymphocytes, and B lymphocytes, promote the secretion of cytokines (e.g., interleukins, tumor necrosis factor), and enhance both non-specific and specific immune functions of the body. Studies show that ginseng polysaccharides can significantly increase immune organ indices (thymus index, spleen index) in normal mice, promote macrophage phagocytic capacity, and enhance lymphocyte proliferation activity. Additionally, ginseng polysaccharides can modulate immune imbalance states, showing a clear restorative effect on immune function in immunosuppressed mice, providing a basis for their application in immunomodulatory functional foods.

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3.2. Antitumor and Adjuvant Function for Radiotherapy/Chemotherapy

Ginseng polysaccharides exert antitumor effects through pathways such as immunomodulation, induction of tumor cell apoptosis, and inhibition of tumor angiogenesis, while also alleviating adverse reactions caused by radiotherapy and chemotherapy. Clinical studies confirm their role as adjuvant drugs in tumor treatment, effectively improving symptoms like leukopenia, fatigue, and loss of appetite, thereby enhancing patients' quality of life and treatment tolerance. For example, ginseng polysaccharide injection is listed in China's national medical insurance reimbursement catalog (Category B) for adjuvant therapy during tumor radiotherapy/chemotherapy. Intramuscular administration can significantly boost immune function and reduce the incidence of adverse reactions. Furthermore, studies have found that ginseng acidic polysaccharides can enhance the antitumor activity of chemotherapeutic drugs, showing promising potential for combination therapies.

3.3. Neuroprotective Function

In recent years, the neuroprotective function of ginseng polysaccharides has garnered widespread attention, showing good potential especially in the prevention and treatment of neurodegenerative diseases like Alzheimer's disease (AD) and Parkinson's disease. Research has found that a ginseng polysaccharide named GP4 with a molecular weight of 4.7 kDa can activate mitochondrial autophagy activity, inhibit β-amyloid (Aβ) aggregation, and alleviate neuroinflammation, thereby improving memory impairment and aging phenotypes in AD model animals[6]. Additionally, a neutral polysaccharide (GB PN) from ginseng berries can activate the Keap1/Nrf2/HO-1/NQO1 signaling pathway, alleviate D-galactose-induced oxidative stress damage, and enhance learning and memory abilities in mice, providing theoretical support for its development in brain health functional foods.

3.4. Antioxidant and Anti-aging Function

Oxidative stress is a key mechanism in body aging and the onset of various diseases. Ginseng polysaccharides possess strong antioxidant activity, exerting anti-aging effects by scavenging free radicals, increasing antioxidant enzyme activity, and inhibiting lipid peroxidation. Studies indicate that ginseng polysaccharides have significant scavenging capacity against DPPH and hydroxyl radicals and can chelate iron ions, reducing reactive oxygen species generation. Simultaneously, ginseng polysaccharides can increase the activity of antioxidant enzymes like superoxide dismutase (SOD) and glutathione peroxidase (GSH-Px) and reduce malondialdehyde (MDA) content in aging model animals, delaying the aging process[7]. Moreover, ginseng polysaccharides can improve skin antioxidant capacity, reduce wrinkle formation, and possess certain beautifying effects.

4. Development and Application of Ginseng Polysaccharide Functional Foods

Based on the multiple biological functions and safety profile of ginseng polysaccharides, they hold broad prospects for development in the functional food field. Currently, the development of ginseng polysaccharide functional foods is mainly concentrated in the health product sector, while their application in conventional foods is gradually expanding, with product forms becoming increasingly diverse.

4.1. Health Products

4.1.1. Oral Preparations

Oral preparations represent the most common and mainstream form of ginseng polysaccharide-based health products available on the market. This category primarily includes oral liquids, capsules, and tablets. These dosage forms offer significant advantages to consumers, such as convenient administration, relatively rapid absorption, and high bioavailability[8]. They are particularly suitable for target populations like individuals with low immunity or patients undergoing tumor radiotherapy and chemotherapy. For users, the key benefits extend to accurate dosing, easy portability, and simple storage. A typical example is commercially available ginseng polysaccharide capsules, which are marketed primarily for immune modulation. By taking them once or twice daily, consumers can effectively support and enhance their body's immune function.

4.1.2. Health Beverages

Health beverages use carriers such as drinking water, fruit juices, and tea drinks, adding ginseng polysaccharides and other functional ingredients (e.g., vitamins, minerals, probiotics) to create beverages with specific health functions. These products have a refreshing taste, are suitable for daily consumption, and appeal to a wide audience. For example, products like ginseng polysaccharide-goji berry oral liquid or ginseng polysaccharide-chrysanthemum tea combine ginseng polysaccharides with traditional medicinal and edible ingredients, offering both nutritional and health benefits, and are well-received by consumers. Additionally, products like ginseng polysaccharide sparkling water or sports drinks can be developed to meet the needs of different groups.

4.2. Conventional Functional Foods

With the popularization of functional foods, the application of ginseng polysaccharides in conventional foods is gradually increasing. By adding them to grain products, dairy products, meat products, pastries, etc., the nutritional and functional profiles of foods are enriched, and product added value is enhanced.

4.2.1. Grain Products

Adding appropriate amounts of ginseng polysaccharides to noodles, bread, steamed buns, and other grain products can improve the texture and flavor of the food while imparting immunomodulatory functions. Studies show that adding 0.5%-1.0% ginseng polysaccharides to noodles can increase their elasticity and cooking resistance, reduce nutrient loss during cooking, and impart no significant off-flavor. Furthermore, products like ginseng polysaccharide-enriched rice flour or dried noodles can be developed for special populations such as the elderly and infants.

4.2.2. Dairy Products

Dairy products are ideal carriers for ginseng polysaccharides. Adding them to milk, yogurt, milk powder, etc., achieves nutritional complementarity and enhances the products' health functions. For example, ginseng polysaccharide yogurt, through probiotic fermentation, retains the nutritional components of milk and the intestinal regulation function of probiotics while adding the immunomodulatory effect of ginseng polysaccharides, suitable for individuals with intestinal dysfunction or low immunity. Ginseng polysaccharide milk powder can be developed for the elderly, pregnant women, and other specific groups, strengthening nutrition and health functions.

4.3. Challenges and Solutions in the Development Process

4.3.1. Existing Challenges

Currently, the development of ginseng polysaccharide functional foods still faces several problems: First, high costs. The large-scale purification process for ginsenoside extraction by-products is not yet perfected, and the production cost of high-purity ginseng polysaccharides is high, limiting their widespread application in conventional foods. Second, limited product forms. Existing products are mostly concentrated in health products like oral liquids and capsules. The depth and breadth of their application in conventional foods are insufficient, and their functional positioning is relatively singular, mostly focusing on immunomodulation. Third, impact on taste. Ginseng polysaccharides have a certain bitterness and off-flavor, which may affect the taste of food products when added, reducing consumer acceptance. Fourth, incomplete regulations and standards. Quality standards and efficacy evaluation systems for ginseng polysaccharide functional foods are not yet sound, making market supervision difficult.

4.3.2. Proposed Solutions

Addressing the above challenges, the following strategies are proposed: First, researchers should optimize purification processes. They should develop efficient, low-cost, large-scale purification technologies, such as integrated membrane separation and bioconversion technologies, to reduce the production cost of high-purity ginseng polysaccharides. Second, manufacturers should innovate product forms. They should expand the application fields of ginseng polysaccharides in conventional foods, combining them with characteristics of different food materials to develop multifunctional composite functional foods across various categories, such as intestinal health foods combining ginseng polysaccharides with probiotics and dietary fiber, or antitumor adjuvant foods combining them with ginsenosides. Third, developers should improve taste. They can mask the bitterness and off-flavor of ginseng polysaccharides by adding sweeteners, flavors, or masking agents, or by using microencapsulation technology to enhance product taste and consumer acceptance. Fourth, relevant authorities should perfect regulations and standards. They should establish quality control standards and efficacy evaluation systems for ginseng polysaccharides, strengthen market supervision, standardize product production and sales, and protect consumer rights.

5. Prospects

The purification of polysaccharides from ginsenoside extraction by-products and the development of functional foods represent important directions for comprehensive utilization of ginseng resources and high-quality development of the ginseng industry. With optimized purification technologies and in-depth biological function research, the industrial production cost of ginseng polysaccharides will gradually decrease, and their application in functional foods will become more widespread. Future research could focus on: First, delving into the structure-activity relationship of ginseng polysaccharides to provide a theoretical basis for targeted functional food development. Second, developing efficient, green large-scale purification processes to achieve low-cost, high-purity production. Third, innovating product development strategies to create diverse, personalized functional foods for different populations. Fourth, strengthening industry-university-research collaboration to promote technological industrialization and improve the industrialization level of high-value utilization of ginseng by-products.

6. Conclusions

Ginsenoside extraction by-products are a rich source of bioactive compounds, particularly ginseng polysaccharides. Efficient extraction methods, such as water extraction enhanced with enzymes, ultrasound, or microwave, yield crude polysaccharides. Purification through techniques like alcohol precipitation, decolorization, resin adsorption, and ultrafiltration improves polysaccharide purity. These purified polysaccharides possess diverse functional properties, including immunomodulation, antitumor adjuvant effects, neuroprotection, antioxidant, anti-aging, and blood glucose regulation, making them ideal for functional food development.

Current applications of ginseng polysaccharides in functional foods include health products like oral liquids and capsules, as well as basic grain and dairy products. However, challenges remain, such as high production costs, limited product variety, taste optimization, and the need for improved regulations. Future prospects depend on clarifying structure-activity relationships, optimizing low-cost large-scale purification, innovating in product design (including composite and personalized products), and strengthening industry collaboration and standardization.

In summary, purifying polysaccharides from ginseng by-products for functional food development supports resource recycling and sustainability. This approach extends the ginseng industry chain, enhances economic returns, and reduces environmental impact. With ongoing technological advances and growing market demand, this field holds broad prospects and significant practical value.

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