

Research on the Recovery and Utilization of Polysaccharides from Ginseng Stem and Leaf Waste and Their Application as Feed Additives

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Abstract: Ginseng, a valuable traditional medicinal herb, is primarily used for its roots, leaving a large amount of stems and leaves discarded as waste, resulting in significant resource waste and environmental pressure. However, these discarded stems and leaves are rich in bioactive components such as polysaccharides, which possess notable immunomodulatory, antioxidant, and growth-promoting functions. Efficient extraction and purification techniques have been developed to obtain these polysaccharides, and their application in animal husbandry demonstrates significant potential as novel functional feed additives. Research has shown that these polysaccharides can significantly enhance the growth performance, improve immune function, and promote intestinal health in livestock, poultry, and aquatic animals, with a favorable safety profile. This high-value transformation of agricultural waste not only extends the ginseng industry chain but also provides an effective antibiotic alternative for green and healthy farming, offering economic, social, and environmental benefits that contribute significantly to promoting sustainable agricultural development.

Keywords: Ginseng stems and leaves, Agricultural waste, Polysaccharide recovery, Feed additive, Resource utilization

1. Introduction: Resource Waste and Opportunities for High-Value Utilization

The development of the ginseng industry primarily relies on its medicinally valuable roots, while the above-ground stems and leaves, which constitute the majority of the plant's biomass, are often treated as agricultural waste after harvest. This traditional practice represents a substantial waste of biomass resources rich in active components, and their accumulation and decomposition may lead to secondary environmental issues. In-depth studies have shown that, in addition to saponins, ginseng stems and leaves contain abundant ginseng polysaccharides. These natural macromolecules have been confirmed to possess broad biological activities and good application safety^[1]. Therefore, the systematic development of ginseng stems and leaves, particularly the targeted recovery and high-value utilization of their polysaccharide components, has become a critical breakthrough for promoting sustainable industrial development and advancing circular agriculture. This study aims to establish a complete technological chain from "waste treatment" to "functional product development." By systematically evaluating its technical feasibility, biological efficacy, and comprehensive benefits, it provides a solid scientific foundation for the industrial application of this green resource, ultimately supporting the green transformation of the feed industry and the practical needs of healthy farming.

2. Recovery Process for Polysaccharides from Ginseng Stems and Leaves

2.1. Raw Material Pretreatment and Basic Extraction

The efficient recovery of polysaccharides from ginseng stems and leaves begins with standardized pretreatment of the raw materials. Fresh stems and leaves must be thoroughly cleaned to remove impurities such as soil, followed by drying under low-temperature or cool, shaded conditions to prevent the degradation of heat-sensitive components. The dried material is then ground into a powder of suitable particle size to obtain a uniform raw material. This step significantly increases the solid-liquid contact area in subsequent extraction processes and is fundamental to improving extraction efficiency.

Traditional hot water extraction is the most direct method for obtaining polysaccharides, utilizing high temperatures to rupture plant cells and dissolve polysaccharides into the aqueous phase. However, this method is often time-consuming, and its extraction yield and polysaccharide activity retention require further improvement^[2].

2.2. Application of Modern Enhanced Extraction Technologies

To overcome the limitations of traditional methods, modern processes widely employ physical or biological enhancement technologies. Ultrasonic-assisted extraction uses cavitation, mechanical vibration, and thermal effects generated by ultrasound in liquids to vigorously disrupt plant cell walls, accelerating polysaccharide dissolution and significantly shortening extraction time while increasing yield. Microwave-assisted extraction leverages the selective heating of polar molecules (such as water) by microwaves, causing rapid internal temperature rise in the material. The resulting increase in internal cell pressure leads to cell structure rupture, achieving efficient and rapid extraction. Additionally, enzymatic-assisted extraction, as a green biotechnology, uses specific enzymes like cellulase and pectinase to hydrolyze cell wall structural polysaccharides, gently releasing the target active polysaccharides. This method offers mild conditions, high selectivity, and better preservation of the polysaccharide's higher-order structure.

2.3. Separation, Purification, and Structural Characterization of Polysaccharides

The crude polysaccharide extract obtained is complex, containing impurities such as proteins, pigments, and inorganic salts, necessitating precise separation and purification to obtain high-purity active products^[3]. First, the concentrated extract typically undergoes ethanol precipitation, a key step for preliminarily separating polysaccharides from other water-soluble small molecules. Subsequently, the crude polysaccharide requires decontamination and refinement. Common methods include the Sevag method (using a chloroform and n-butanol mixture to remove proteins via shaking) or the trichloroacetic acid method for deproteinization, along with decolorization using activated carbon adsorption or hydrogen peroxide oxidation. To obtain fractions with uniform molecular weight or charge, column chromatography techniques are often employed, such as separation based on charge differences using ion-exchange resins like DEAE-cellulose or size-based fractionation using Sephadex series gels. Systematic structural characterization is essential for the purified polysaccharide product. This includes determining molecular weight and distribution using High-Performance Gel Permeation Chromatography (HPGPC), analyzing characteristic functional groups (such as hydroxyl groups and glycosidic bonds) using Infrared Spectroscopy (IR), analyzing monosaccharide composition and molar ratios using Gas Chromatography (GC) or High-Performance Liquid Chromatography (HPLC), and employing Nuclear Magnetic Resonance (NMR) spectroscopy for in-depth analysis of glycosidic bond types, linkage sequences, and spatial conformations within the sugar chains. This characterization work is necessary to clarify its material basis, establish quality standards, and correlate it with biological activity.

3. Core Biological Activities of Polysaccharides from Ginseng Stems and Leaves

3.1. Immunomodulatory Function

One of the most significant functions of polysaccharides from ginseng stems and leaves is their ability to modulate the immune system. Studies show that they can activate macrophages, enhancing their phagocytic capacity and antigen-presenting function, and promote the release of immune mediators such as nitric oxide and tumor necrosis factor- α . Simultaneously, they can stimulate the proliferation and differentiation of T and B lymphocytes, promote the generation of antibodies (e.g., IgG, IgM), and regulate the balance of Th1/Th2 cytokines, such as promoting the secretion of interferon- γ and interleukin-2. This comprehensively enhances both cellular and humoral immune responses, improving the body's resistance to pathogenic infections.

3.2. Antioxidant and Anti-inflammatory Effects

These polysaccharides possess potent antioxidant capabilities. On one hand, the active groups in their molecular structure can directly scavenge reactive oxygen species such as superoxide anions and hydroxyl radicals. On the other hand, they can upregulate the activity of endogenous antioxidant

enzymes like superoxide dismutase, catalase, and glutathione peroxidase in animals by activating signaling pathways such as Nrf2/ARE and reduce the generation of malondialdehyde, an end product of lipid peroxidation, thereby systematically alleviating oxidative stress damage. Their anti-inflammatory effects are closely linked to their antioxidant properties. They primarily function by inhibiting the over-activation of key inflammatory signaling pathways like nuclear factor-kappa B and mitogen-activated protein kinases, downregulating the expression of cyclooxygenase-2 and inducible nitric oxide synthase, and reducing the production of pro-inflammatory factors such as prostaglandin E2, interleukin-1beta, and interleukin-6, thus effectively controlling inflammatory responses.

3.3. Regulatory Mechanisms on Intestinal Health

As high-quality prebiotics, polysaccharides from ginseng stems and leaves are crucial for maintaining intestinal microecological balance and barrier function. They can resist digestion in the upper gastrointestinal tract, reaching the hindgut intact, where they are selectively utilized by beneficial bacteria like Bifidobacterium and Lactobacillus, promoting their proliferation and the production of short-chain fatty acids (e.g., acetate, propionate, butyrate)^[4]. These short-chain fatty acids not only lower intestinal pH, inhibiting the growth of harmful bacteria such as Escherichia coli and Salmonella, but also provide energy for colon epithelial cells, promote mucus secretion, and enhance the expression of tight junction proteins (e.g., Occludin, ZO-1), thereby strengthening the physical barrier of the intestinal mucosa^[5]. The combined action of a healthy gut microbiota and an intact intestinal barrier effectively reduces endotoxin translocation and exerts positive regulatory effects on systemic immunity and metabolic homeostasis through multiple pathways, including the gut-immune axis and gut-liver axis.

3.4. Anti-stress Effects and Improvement of Product Quality

Beyond direct immune and intestinal regulation, polysaccharides from ginseng stems and leaves exhibit notable efficacy in alleviating animal stress. During farming, animals often face stressors such as transportation, regrouping, high temperatures, and high density, leading to elevated glucocorticoid levels, exacerbated oxidative stress, and temporary immunosuppression. Studies show that these polysaccharides can regulate the stress response via the hypothalamic-pituitary-adrenal axis, lowering serum cortisol levels, while their potent antioxidant system scavenges excess free radicals generated by stress, maintaining body homeostasis. This characteristic is significant for reducing stress-induced diarrhea, improving animal welfare, and enhancing production stability. Furthermore, their anti-stress and antioxidant effects directly contribute to improving the quality of livestock and aquatic products. In broiler and swine feeding, supplementing with these polysaccharides can reduce drip loss in post-slaughter muscle, increase pH, delay post-mortem glycolysis, thereby improving meat color and tenderness. In aquaculture, they can mitigate muscle deterioration in fish during transportation and processing, preserving the bright appearance and elasticity of the fish.

4. Application Research in Animal Husbandry as a Feed Additive

4.1. Comprehensive Benefits in Livestock and Poultry Farming

Supplementing diets of livestock and poultry, such as pigs, chickens, and ruminants, with appropriate doses of polysaccharides from ginseng stems and leaves has been confirmed to yield multifaceted production benefits^[6]. Regarding growth performance, they can increase average daily gain and reduce the feed-to-gain ratio, potentially through mechanisms involving improved intestinal morphology, enhanced digestive enzyme activity, and regulated energy metabolism. In health management, their immune-enhancing effects translate directly into economic benefits, manifested as elevated antibody levels in animal groups, improved immune organ indices, enhanced vaccine efficacy, and significantly reduced incidence and mortality of respiratory and digestive diseases, leading to decreased antibiotic use^[7]. Additionally, regarding product quality improvement, these polysaccharides help reduce slaughter stress, improve muscle water-holding capacity and tenderness, and increase the content of flavor amino acids and unsaturated fatty acids in muscle, thereby enhancing the sensory quality and nutritional value of meat products.

4.2. Application Advantages in Aquaculture

Aquatic animals heavily rely on non-specific immune systems, and polysaccharides from ginseng stems and leaves serve as effective immunostimulants. Adding them to fish and shrimp feed not only promotes feeding and growth but also significantly enhances tolerance to environmental stressors such as hypoxia, ammonia nitrogen, and sudden salinity changes^[8]. Their core value lies in comprehensively activating the innate immune defense system: significantly increasing the activity of lysozyme and alkaline phosphatase in serum and surface mucus; activating the complement system; and enhancing the respiratory burst activity and phagocytic capacity of macrophages and neutrophils. This enables farmed species to exhibit higher survival rates and stronger resistance when confronted with bacterial pathogens like *Aeromonas hydrophila* and *Vibrio*, as well as viral threats such as iridovirus and nervous necrosis virus.

4.3. Core Mechanism of Action: The "Gut-Immune Axis" Theory

Whether in livestock, poultry, or aquatic animals, a core mechanism through which polysaccharides from ginseng stems and leaves exert their effects is believed to involve the "gut-immune axis". Polysaccharides modulate gut microbiota composition, increasing the abundance of beneficial bacteria. Their metabolites, such as short-chain fatty acids, not only nourish the gut but also enter the bloodstream, directly or indirectly influencing distal immune organs^[9]. For example, butyrate has been shown to regulate the differentiation of regulatory T cells, thereby participating in systemic immune tolerance. Simultaneously, a healthy intestinal barrier reduces the translocation of pathogens and endotoxins, lowering systemic inflammation levels. Therefore, their action is not limited to a single target but involves reshaping the gut microecology, triggering a cascade of reactions that ultimately lead to systemic improvement of the organism's overall growth and health status.

5. Analysis of Key Issues in Industrial Application

5.1. Safety Evaluation and Palatability

Any novel feed additive must undergo rigorous safety assessment before market introduction. Existing toxicological studies, including acute and subchronic toxicity tests, indicate that polysaccharides from ginseng stems and leaves are practically non-toxic. Long-term use within recommended dosage ranges shows no adverse effects on the growth, hematological, physiological, biochemical parameters, or major organ histology of experimental animals, confirming high food safety. Regarding palatability, these polysaccharides themselves have no undesirable odor. Adding appropriate amounts (typically within 0.02%–0.2%) to feed does not cause feed rejection by animals; some studies even suggest improved palatability, possibly due to their role in enhancing intestinal comfort.

5.2. Application Technology and Compatibility

In practical production, determining the optimal additive dosage for different animal species and growth stages requires exploration through systematic dose-response experiments. Simultaneously, investigating their synergistic effects with probiotics, acidifiers, enzyme preparations, or other plant extracts to develop compound functional feed products is an effective approach to enhance application efficacy and added value. During feed processing, attention must be paid to the potential impact of high temperature and pressure during pelleting on the molecular structure and activity of polysaccharides. Adopting strategies such as low-temperature pelleting, post-pelleting spray coating technology, or preparing polysaccharides into stable microencapsulated formulations is crucial for preserving their bioactivity in the final product.

5.3. Techno-Economic and Environmental Benefit Assessment

From an economic perspective, using waste as raw material significantly reduces the cost base. Although extraction and purification processes involve energy consumption and equipment investment, the final product offers high added value and can yield indirect economic returns by reducing veterinary drug costs and improving farming efficiency, rendering it overall market-viable. From an industrial chain perspective, it transforms the "disposal link" at the end of the traditional industry chain into a new "value-added link," enhancing the resilience and comprehensive profitability of the entire

industry. Regarding environmental benefits, this technology directly achieves resource utilization of agricultural waste, avoiding soil, water, and air pollution associated with landfilling or incineration, reducing greenhouse gas emissions, and conserving resources and energy otherwise consumed in producing similar functional products, such as some chemically synthesized additives. It represents a typical model of green circular agriculture, holding positive significance for promoting sustainable development in the farming industry.

6. Challenges and Future Prospects

6.1. Current Main Bottlenecks

Despite its considerable potential, the industrialization of this technology still faces several challenges. First, technology scale-up and standardization present difficulties. Maintaining the stability, efficiency, and cost-effectiveness of laboratory-optimized processes in large-scale production requires addressing issues such as engineering equipment selection and process parameter control. Second, scientific understanding needs further deepening. Currently, there is a lack of systematic and in-depth research on the precise structure-activity relationships of polysaccharides, their metabolic fate within complex animal organisms, and their interaction mechanisms with other feed components. Third, industry standards and regulations are lacking. Quality standards, testing methods, safety evaluation norms, and usage guidelines for this feed ingredient urgently need to be established to regulate the market and ensure product effectiveness and safety. Finally, market awareness and acceptance require time to cultivate. Extensive demonstration applications and reliable data are needed to prove its return on investment and drive market adoption.

6.2. Future Research Directions and Development Prospects

Future research should focus on: developing more efficient, energy-saving, and intelligent integrated extraction and purification equipment and processes; utilizing multi-omics technologies such as metabolomics, metagenomics, and proteomics to elucidate their multi-target action networks within animals in depth; and promoting the establishment of national or industry standards to improve the regulatory framework. From an industrial development perspective, exploring the comprehensive utilization of all components in ginseng stems and leaves—simultaneously developing various products like polysaccharides, saponins, and dietary fibers for diverse markets such as feed, food, and health supplements—can maximize resource value. Through deep integration of "industry, academia, research, application, and finance", establishing full industrial chain demonstrations from cultivation, collection, and storage to processing and feed application is expected to accelerate the transformation and implementation of this green scientific and technological achievement. It holds the potential to become a key supporting technology for ensuring food security, promoting emission reduction and efficiency enhancement in animal husbandry, and achieving agricultural resource recycling.

7. Conclusions

The resource utilization of ginseng stem and leaf waste, particularly the recovery of active polysaccharides and their application in feed, represents an innovative endeavor that integrates scientific, economic, and ecological benefits. Systematic research indicates that modern biotechnology enables the efficient extraction of polysaccharides from ginseng stems and leaves. These polysaccharides exhibit multiple well-defined biological functions, including immune enhancement, antioxidant activity, and intestinal health regulation. Their antioxidant mechanism has been experimentally validated, demonstrating the ability to alleviate oxidative damage in animal tissues by enhancing the activity of antioxidant enzymes such as SOD and reducing MDA levels; The immunomodulatory effects have also been thoroughly verified through pathways such as activating immune cells and promoting cytokine secretion^[10]. When used as a functional feed additive in livestock, poultry, and aquaculture, these polysaccharides can effectively improve animal production performance, enhance disease resistance, and elevate product quality, with a high safety profile. This approach successfully transforms an environmental burden into an industrial advantage, not only providing an effective solution for enhancing the value of the entire ginseng industry chain and promoting circular agriculture but also opening new pathways for the animal farming industry to seek green and safe alternatives to antibiotics.

However, the successful promotion of this technology still depends on systematic optimization and collaborative innovation across the entire chain. At the basic research level, future efforts should further elucidate the structure-activity relationships between polysaccharide molecular structures and specific biological activities and clarify their complex metabolic pathways and signaling regulatory networks within animals to provide a theoretical basis for their precise application. At the technology development level, efforts should focus on advancing the integration, intelligence, and low-carbon transformation of extraction and purification processes to reduce production costs and ensure product stability. Simultaneously, developing specialized formulations (e.g., microcapsules, nanocarriers) suitable for different farming subjects and stages is necessary to improve their bioavailability in complex feed systems and within animals. At the industrial integration level, it is essential to build an industrial chain alliance encompassing standardized collection in ginseng cultivation areas, raw material pretreatment, centralized processing, and targeted supply of feed products to achieve large-scale and standardized efficient resource utilization. Furthermore, accelerating the establishment of a complete standard system—including raw material quality standards, testing methods, safety evaluation procedures, and technical guidelines for use—is critical for facilitating the legal and compliant market entry of this product and gaining user trust.

In the long term, the comprehensive utilization of ginseng stems and leaves should not be limited to polysaccharides alone. Advocating an "integrated utilization" concept by simultaneously developing other active substances they contain, such as saponins, flavonoids, and dietary fibers, for diverse markets like feed, food, and health supplements can maximize resource value. Through the combined efforts of policy guidance, scientific and technological support, and market drivers, this green technology has the potential to become a model linking the circular use of traditional Chinese medicinal resources with modern healthy farming. It would not only provide a robust tool for ensuring animal husbandry production safety and improving the quality of animal-derived food but also contribute practical solutions to addressing resource constraints, promoting the green transformation of agricultural systems, and achieving "dual carbon" goals. Ultimately, the maturation and promotion of this circular economy model will vividly demonstrate the sustainable development philosophy of "turning waste into treasure and harm into benefit," generating profound and positive impacts across social, economic, and ecological dimensions.

References

- [1] Chen Q, Liu J C. Research progress on ginseng polysaccharide, astragalus polysaccharide and lycium barbarum polysaccharide[J]. *Journal of Huainan Normal University*, 2001, (2): 39-41.
- [2] Wang Y M, Wang X L. Research progress on extraction, isolation and pharmacological effects of ginseng polysaccharide[J]. *Journal of Northeast Agricultural Sciences*, 2021, (2): 103-107.
- [3] Li J, Wang D, Xing X, et al. Structural analysis and biological activity of cell wall polysaccharides extracted from *Panax ginseng* marc[J]. *International Journal of Biological Macromolecules*, 2019, 135: 29-37.
- [4] Shi Y, Zheng S, Xie K, et al. Regulatory effects of ginseng polysaccharide on growth restriction and intestinal dysfunction caused by a high cottonseed meal diet in *Ctenopharyngodon idella*[J]. *International Journal of Biological Macromolecules*, 2025, 322(Pt 1): 146727.
- [5] Gao Y, Guo M, Chen J, et al. A ginseng polysaccharide protects intestinal barrier integrity in high-fat diet-fed obese mice[J]. *International Journal of Biological Macromolecules*, 2024, 277(Pt 1): 133976.
- [6] Zhang F Y, Shi X Z, Zhao Z L, et al. Effects of ginseng processing by-products on saponin accumulation in muscle and eggs of Jilin Luhua chickens[J]. *Journal of Northeast Agricultural Sciences*, 2022, 47(4): 83-87.
- [7] Liu J, Wang H, Luo J, et al. Synergism of fermented feed and ginseng polysaccharide on growth performance, intestinal development, and immunity of Xuefeng black-bone chickens[J]. *BMC Veterinary Research*, 2024, 20(1): 13.
- [8] Yang J, Wu P, Jiang W, et al. A new vision of *Panax ginseng* leaf polysaccharide function: multiple roles in improving growth, flesh quality and muscle energy metabolism of sub-adult grass carp (*Ctenopharyngodon idella*)[J]. *Journal of Animal Science and Biotechnology*, 2025, 16(1): 149.
- [9] Wang N, Xin Y. Review: Gut microbiota: Therapeutic targets of ginseng polysaccharides against multiple disorders[J]. *International Journal of Biological Macromolecules*, 2025, 287: 138527.
- [10] Wang H, Peng D, Xie J. Ginseng leaf-stem: bioactive constituents and pharmacological functions[J]. *Chinese Medicine*, 2009, 4: 20.