Development and Exploration of Functional Foods

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Abstract. In recent years, with increasing health awareness and the population aging, the field of functional foods has developed rapidly. This article reviews the definition and mechanisms of functional foods, as well as their effects on immunity, metabolism, cardiovascular health, and nervous system. It systematically summarizes the extraction and purification technologies of functional ingredients, including solvent extraction, enzyme-assisted extraction, and supercritical fluid extraction. Finally, it discusses future prospects for advancing the personalized nutrition are discussed.

Keywords: functional foods; mechanism; extraction and purification

1 Introduction

As the global population ages, food demand has shifted from meeting basic nutritional needs to the regulating and optimizating specific physiological functions. Functional foods, with their dual characteristics of "food attributes" and "functional attributes," have become a bridge connecting traditional food and healthcare [1]. Functional foods are foods that provide basic nutrition while also containing bioactive components that benefit human health or reduce disease risk. This indicates that functional foods are not only an extension of ordinary foods but also an important outcome of the of nutrition and food science. Because they provide specific physiological functions, they have gradually gained consumer attention and recognition.

The market prospects of functional foods are first reflected in increasingly diverse consumer demands and innovation across different consumption scenarios. As overall health awareness significantly increases, consumers' focus on food has gradually shifted from simply "eating enough and eating well" to "eating for health" and "eating for effects." People's consumption behavior has also changed from passive treatment to active prevention [1]. Moreover, as public health awareness grows, health maintenance needs have expanded from the "silver-haired group" to the "younger generation." Currently, young people have become the main force in health maintenance consumption.

In addition to changes in consumer demand, the pandemic has significantly increased consumer attention to functional foods. According to data from Japan's Health Industry News, the health food market, including functional foods, experienced sig-

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nificant growth after the pandemic. Specifically, the market size of foods for specified health use reached 649.3 billion yen, while that of functional labeled foods reached 264.0 billion yen. This large market mainly benefited from substantially increased orders from overseas markets such as China [2].

Domestically, functional foods are also thriving due to policy support. In recent years, with the advancement of the national health strategy and policy support such as the Food Safety Law, the development of medicinal and edible ingredients in functional foods and ready-to-eat medicinal meals has accelerated.

The development of functional foods has important theoretical and practical significance. This is because their development provides new ideas for the research of drugs to treat certain diseases. For example, Zhang Yunhe et al. mentioned that-PuerariaandAstragalusare typical medicinal and edible herbs. The bioactive components they contain provide ideas for the development of drugs to prevent Alzheimer's disease. Furthermore, adding functional substances to common foods gives them functionality. This allows people to improve their health status and even prevent certain diseases through their daily diet.

2 Classification and Mechanisms of Functional Foods

Functional foods mainly exert their effects through bioactive components such as polysaccharides, prebiotics, and proteins. Functional polysaccharides often possess various biological activities due to their special structures. For example,Ganodermapolysaccharides contain β-glycosidic bonds, which make them resistant to degradation by human digestive enztmes. Therefore, they can bind to immune cells and inhibit cancer cell growth. Meanwhile, their unique branched structure and helical conformation also give them distinctive biological activities [3].

Compared with functional polysaccharides, the functions of prebiotics mainly stem from their incomplete digestion in the intestine. They can selectively promote the growth of beneficial gut bacteria. Additionally, some prebiotics can be broken down into short-chain fatty acids. These acids change the intestinal pH, provide energy for the gut microbiota, or promote mineral absorption in the intestine.

Protein-based functional foods not only provide energy but also help prevent diseases and enhance immunity due to their special structures.

Although functional foods contain bioactive components, they sometimes fail to exert expected effects in the human body. This is because many active factors are easily degraded or must act at specific absorption sites. For example, the effectiveness of probiotic functional foods often depends on the number of probiotics that reach the intestine. The pH environment in other parts of the digestive tract may kill these probiotics. Therefore, improving utilization rate is an important research direction in actual production.

For instance, composite encapsulation technology can significantly enhance the functionality and utilization rate of probiotics. This provides additional advantages for functional food development. Besides composite encapsulation, nanomaterials such as nanoliposomes and nanocapsules can improve the performance of functional ingredients that are easily decomposed, highly volatile, or strongly irritating [4]. Some emerging technologies, such as 3D printing, also show great potential for controlled release of functional ingredients by forming different gel structures.

3 Effects of Functional Foods on Human Health

The immune system is an important defense system of the human body. It plays a key role in fighting external pathogens and internal tumors. Among current health concerns of young people, declining immunity ranks third. More than 40% of young people worry about their weakened immunity. This shows that reduced immunity has become a common phenomenon among the youth. Since functional foods can help enhance immunity to some extent, they are highly favored by young consumers.For example, foods containing probiotics such as Lactobacillus can stimulate immune cells to produce secretory immunoglobulin A. This enhances the body's ability to eliminate pathogenic microorganisms and allergens. This mechanism mainly depends on the interaction between microbial metabolites and pattern recognition receptors. It also involves the regulation of downstream immune signaling pathways. The Notch signaling pathway plays an important role in immune regulation and cell differentiation. Its abnormal activation is closely related to the occurrence of autoinflammatory diseases. Studies have found that prebiotics can regulate the Notch signaling pathway. They reduce the production of pro-inflammatory factors and enhance anti-inflammatory functions [5].

Metabolism is the fundamental driving force for the body to maintain life and adapt to environmental changes. It runs through all physiological processes, including energy management, material circulation, immune defense, and gene regulation. Dietary fiber in functional foods can effectively improve metabolic status. It lowers blood glucose levels and promotes fat metabolism. Foods high in dietary fiber can prevent large blood glucose fluctuations. This reduces the risk of diabetes. Dietary fiber can also be broken down into short-chain fatty acids in the large intestine. Research by Lucas et al. [6] showed that short-chain fatty acids regulate bone metabolism. In their experiment, mice were fed with water containing acetic acid, propionic acid, and butyric acid for eight weeks. Results showed that compared with the control group, the experimental group had significantly lower levels of CTX-I, a bone resorption marker. The number of osteoclasts decreased. Overall bone mass also showed an increasing trend.

Middle-aged and elderly people are at high risk for cardiovascular and cerebrovascular diseases. Common diseases include coronary heart disease, hypertension, and stroke. Excessive cholesterol intake increases the risk of these diseases. Functional foods containing phytosterols can help. These substances inhibit cholesterol absorption in the intestine. In an experiment by Ming et al. [7], mice were fed with phytosterol-supplemented food. Their total cholesterol levels decreased, while high-density lipoprotein cholesterol increased. This suggests that foods with phytosterols can reduce the risk of cardiovascular and cerebrovascular diseases. They may also protect the liver and blood vessels.

The nervous system is the body's regulatory center. It coordinates all physiological and psychological activities. Maintaining nervous system health is very important. Beneficial components in functional foods, such as puerarin, can improve nervous system health. Puerarin improves neurological function and delays Alzheimer's disease progression through multi-target synergistic mechanisms. Its core effects include reducing oxidative stress and inhibiting neuroinflammation.Puerarin activates the Nrf2/ARE signaling pathway. This enhances the antioxidant defense of nerve cells.

It also inhibits the NF-κB signaling pathway. This reduces the release of pro-inflammatory factors. In regulating key pathological aspects of Alzheimer's disease, puerarin inhibits BACE1 and γ-secretase activity. This reduces the production of β-amyloid protein. It also inhibits GSK-3β activity. This reduces abnormal phosphorylation of Tau protein. Additionally, puerarin regulates neurotransmitter balance. It improves cholinergic system function and alleviates glutamate excitotoxicity. It also promotes the expression and secretion of neurotrophic factors. Through these multiple pathways, puerarin exerts its neuroprotective effects [8].

4 Development Technologies of Functional Foods

The development of functional foods cannot bypass the extraction and purification of functional ingredients from raw materials. During the development process, functional ingredients should first be extracted. The extraction methods for functional ingredients include traditional approaches and emerging techniques. Traditional methods include solvent extraction and enzyme-assisted extraction.Solvent extraction is widely used to extract functional substances from raw materials. For example, when extracting anthocyanins, methanol, acetone, or their mixtures can be used to dissolve and filter anthocyanins from materials. The pH can be adjusted to extract anthocyanins. Solvent extraction is also a common method for extracting polysaccharides from plants. Solvent extraction has its advantages, such as no need for special equipment and low cost. However, this method often has low extraction efficiency and is time-consuming. Enzyme-assisted extraction involves adding appropriate enzymes during the extraction process. It uses the high selectivity of enzyme catalysis to decompose plant tissues while retaining active ingredients in the extract. This achieves rapid and effective extraction. Wang et al. [9] used enzyme-assisted extraction to obtain taxifolin and flavonoids from larch. These are natural antioxidants. The yield was 20% to 30% higher than traditional hot water extraction. This shows that enzyme-assisted extraction generally has higher yield and efficiency than solvent extraction.Besides these methods, some emerging techniques in the food field are also often used for extracting functional ingredients. These include microwave extraction, ultrasonic extraction, and supercritical CO_2 extraction.Microwave extraction uses the strong penetrating power of microwaves and the energy they generate to promote molecular motion, thereby achieving heating. Liazid et al. [10] used microwave extraction to obtain anthocyanins from purple grapes. The yield was significantly higher than traditional hot water extraction. Milutinović et al. [11] used response surface methodology to optimize microwave-assisted extraction of polyphenols and flavonoids from yarrow. They obtained large amounts of product in only 33 seconds, while traditional maceration extraction required 48 hours.Ultrasonic-assisted extraction mainly uses the combined effects of ultrasound, including cavitation, thermal effects, vibration, disruption, and mixing. These effects destroy plant cell walls, enabling the extraction of active ingredients from natural materials. Sun Xiangming [12] used ultrasonic-assisted extraction to obtain flavonoids from marigold. The total flavonoid content reached 53.23 mg·g^{-1}, while reflux extraction yielded only 38.40 mg·g^{-1}.Supercritical fluid extraction uses the special physical and chemical properties of CO_2 above its critical point. By controlling parameters such as temperature and pressure, it achieves efficient separation of target compounds. Compared with traditional solvents, using supercritical fluids as extractants for active ingredients in traditional Chinese medicine has multiple advantages. Due to its high diffusivity and low viscosity, supercritical fluid can quickly penetrate into the pores of complex matrices. This greatly improves extraction efficiency. Supercritical fluid extraction has unique advantages in extracting volatile components, fat-soluble components, heat-sensitive components, and active ingredients from valuable medicinal materials. Taking camellia oil processing as an example, solvent extraction may leave toxic substances such as organic solvents and benzopyrene. Supercritical fluid extraction does not have this problem [13]. This shows that when extracting some functional substances, the purity achieved by supercritical fluid extraction is significantly higher than other methods.In summary, among common extraction methods, traditional methods generally have low yields or long production times. This may increase the difficulty of production control. New methods generally have higher production efficiency and yields. However, traditional methods have lower equipment requirements and costs. In actual production, the specific choice should be based on the properties of the functional substances to be extracted.

Purification is an indispensable step in functional food production. Traditional purification methods usually include liquid-liquid extraction and crystallization.Liquid-liquid extraction, also called solvent extraction, uses two immiscible or partially miscible liquid phases. It allows solutes from one liquid phase to redistribute between the two phases, achieving separation. Chen Haiguang et al. [14] used ethyl acetate and anhydrous ether (1:1, volume ratio) to extract polyphenols from mangosteen peel aqueous extract. The total phenol content in the aqueous phase was 20.4 mg GAE/g FW, while that in the organic phase was 16.5 mg GAE/g FW.Crystallization is a classic separation and purification technique. It uses differences in substance solubility. By controlling temperature, concentration, solvent, and other conditions, target components are precipitated from solution as crystals. Liu Wenting et al. [15] purified 1,8-cineole using crystallization. The operating conditions were final crystallization temperature of −25°C, cooling rate of 4°C/h, sweating rate of 4°C/h, final sweating temperature of −6°C, and addition of 0.2% unmilled seed crystals at −17°C. Under these conditions, the product purity reached 89.63%. This result shows that for extracting 1,8-cineole, one-step crystallization outperformed general batch distillation and molecular distillation methods.Emerging purification methods include membrane separation technology, column chromatography, and high-performance liquid chromatography.Membrane separation technology achieves separation based on differences in dissolution and diffusion rates of mixture components in the membrane, or the membrane's selective adsorption and sieving effects. Membrane separation technology has the advantages of no chemical reagents required, simple equipment, and easy-operation. Chen Weiping [16] used membrane separation technology to purify total alkaloids from Tripterygium hypoglaucum root extract. The average impurity removal rate across three batches reached 96.87%. Column chromatography works by differences in molecular size, charge, and polarity among components. When the mobile phase passes through the stationary phase, components have different retention times, achieving separation [15]. High-performance liquid chromatography separates components based on differences in their partition coefficients between the stationary phase and mobile phase. Due to different processing capacities of various methods, combining purification methods is very common.

5 Conclusions

In summary, functional foods play a significant role in improving human health, promoting chronic disease prevention, and promoting the transformation and upgrading of the food industry. Future research should continue to deepen the understanding of functional mechanisms, enhance the stability of bioactive ingredients, and advance the personalized nutrition system. At the same time, addressing key challenges—such as flavor optimization, personalization strategies, and integration with smart health technologies—will be essential for translating scientific advances into successful commercial products. These combined efforts will support the sustainable growth of the functional food industry and better meet the evolving health needs of consumers.

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