Proceedings of the 5th International Conference on Modern Medicine and Global Health
DOI: 10.54254/2753-8818/2027.38498

Research Report on the Effective Nutritional Chemical Components and Functions of Dendrobium

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Abstract. This study systematically reviewed the main effective nutritional and chemical components of plants in the genus Dendrobium through literature searches, data collection, organization and analysis. Six main categories of components were summarized. Polysaccharides have biological activities such as immunomodulatory and antioxidant effects. Alkaloids show biological activities such as anti-inflammatory and neuroprotective effects. Bibenzyl compounds have good anti-tumor and antioxidant potential. Flavonoids show antioxidant and anti-inflammatory activities. Amino acids, phenolic acids and volatile components have high nutritional value and physiological activities. Trace elements also provide support for the nutritional functions of Dendrobium. At the same time, different varieties, cultivation methods, plant parts and harvesting periods can significantly affect the content of active components in Dendrobium. This study clarifies the composition characteristics and functional activities of the main effective nutritional and chemical components of Dendrobium. It provides a reference for the scientific development of Dendrobium resources, quality evaluation, and the research and application of products with both medicinal and edible value.

Keywords: Dendrobium, medicinal and edible value, nutritional chemical components, active components

1. Introduction

The concept of "medicine and food sharing the same origin" has been recognized since the 1930s. With increasing public health awareness, the development of resources with both medicinal and edible value has gained significant opportunities. Dendrobium is a traditional medicinal and edible plant in China, included in the 2020 edition of the Chinese Pharmacopoeia, with functions such as nourishing yin, promoting body fluid production, and regulating immunity [1].

Studies have shown that Dendrobium mainly contains polysaccharides, alkaloids and other nutritional and active components. It has become an important source for research on natural functional foods in recent years. These components work together and show various biological functions, such as yin nourishment, fluid generation and immune function regulation [2]. However,most current studies relies on in vitro cell and animal models,with clinical studies remaining limited.Research outcomes also vary, largely due to differences in cultivation techniques, plant tissues, and species, which alter the plant's nutritional profile.

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DOI: 10.54254/2753-8818/2027.38498

2. Main effective nutritional chemical components of dendrobium

Dendrobium polysaccharides are the most abundant and biologically significant macromolecular compounds in Dendrobium. Their monosaccharide composition mainly includes mannose, glucose, and galactose. The primary fine structure is glucomannan, with a main chain connected by β-1,4 glycosidic bonds and O-acetyl groups on side chains. Structural composition and modification patterns differ significantly among species, providing a structural basis for diverse biological activities [3]. In addition to the common glucomannan, they also contain relatively high proportions of glucose, galactose, mannose, xylose, arabinose, rhamnose, glucuronic acid and galacturonic acid. The main glycosidic linkages include (1→4)-β-D-Glcp, (1→4)-α-D-Glcp, (1→6)-α-D-Glcp and (1→4)-β-D-Manp [4]. These variations in monosaccharide composition and glycosidic bond types may further contribute to the diverse biological activities of Dendrobium polysaccharides.

The crude polysaccharide DOP from Dendrobium officinale can be separated into one neutral sugar (DOP-1) and five acidic sugars through DEAE-cellulose ion-exchange chromatography and gel permeation chromatography. Among them, DOP-1-A1 is rich in mannose and acetyl groups, with a high degree of polymerization and low branching [5]. Its repeating structural unit is shown in Figure 1 [4].

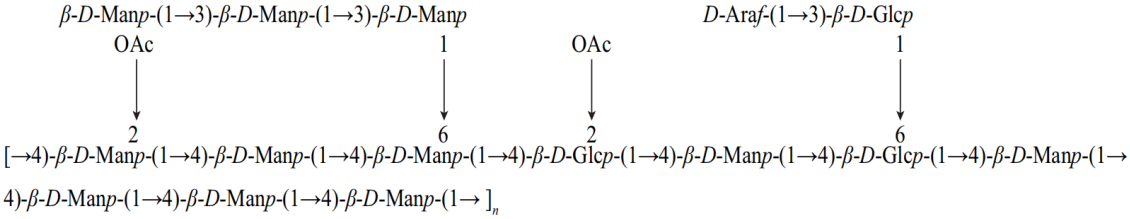

Figure 1. Repeating structure of DOP-1-A1 [4]

Dendrobium polysaccharides, including DOP-1, DOPP-1, and CDOP-1, can directly scavenge reactive oxygen species such as $O_2^{-}\cdot$, ·OH, and H_2O_2 [5], showing strong antioxidant activity. They can also significantly inhibit hemolysin formation and complement activity, contributing to anti-inflammatory effects.

Alkaloids were the first group of compounds isolated from Dendrobium and are widely found in species including Dendrobium nobile, D. moniliforme, D. findlayanum, D. hancockii, and D. roseum [6]. They can be divided into five types: sesquiterpenes, octahydroindolizines, pyrrolidines, amides, and imidazoles. Alkaloids in Dendrobium officinale are mainly amide alkaloids [7].

From a structure-activity perspective, the biological activities of alkaloids are closely related to their skeleton structures, functional groups, and stereochemical configurations [8]. Taking Dendrobium nobile as an example, 25 alkaloids have been reported, including sesquiterpene alkaloids (dendrobine-type and dendramine-type), amide alkaloids, and adenosine-type compounds. In dendrobine-type compounds, C3-OH and C15-COOH form a five-membered lactone ring, while N and C2/C10 form a nitrogen-containing heterocyclic ring, with N usually bearing a methyl group.

Sesquiterpene alkaloids are common in Dendrobium and found in large amounts in D. nobile. Picrotoxane-type sesquiterpenes contain multiple chiral centers [9]. Thirteen picrotoxane-type alkaloid sesquiterpenes and 18 non-alkaloid compounds have been isolated from D. nobile [10]. Pyrrolidine alkaloids are relatively rare, with only five reported in Dendrobium, all as simple phthalide-pyrrolidine alkaloids. Only five pyrrolidine alkaloids have been reported in Dendrobium, and all of them are simple phthalide-pyrrolidine alkaloids. Shihunine was the first pyrrolidine

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alkaloid discovered from Dendrobium lohohense in 1968, followed by shihunidine from the same species. Four isomeric alkaloids, including dendrochrysines (3 and 4) and dendrochrysanines (5 and 6), were later isolated from Dendrobium thyrsiflorum, and hygrine (7) was also found in Dendrobium lohohense [11]. Their specific structures are shown in Figure 2.

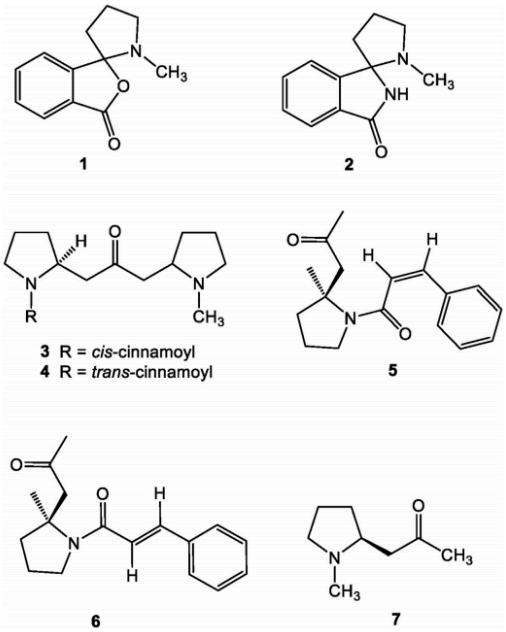

Figure 2. Chemical structures of pyrrolidine alkaloids

Dendrobium alkaloids have attracted attention due to their unique structures and biological activities. Most alkaloids in D. officinale show hydroxyl radical scavenging activity, with antioxidant, anti-neuronal apoptosis, cardiovascular protective, and potential anti-diabetic effects [7]. Research also indicates that Dendrobium alkaloids can reduce depression-like behaviors and neuronal damage caused by chronic stress [12].

Stilbenoid compounds are relatively abundant aromatic compounds in Dendrobium, mainly including phenanthrenes and bibenzyls. A range of 9,10-dihydrophenanthrene derivatives,such as crepidatin, confusarin, erianin, and moscatilin A-occur naturally across various Dendrobium species [13].

Characterized by a core 1,2-diphenylethane backbone, bibenzyls constitute one of the most abundant phenolic classes in D.They have simple basic structures,diverse substituents and various skeleton connections [14]. Structurally, bibenzyls consist of two benzene rings,which are linked by a central 1,2-diphenylethane backbone.Dendrobibenzyl, dihydroresveratrol, and gigantol are the main representatives and its specific chemical structures are detailed in Figure 3. Among these, gigantol serves as a prototypical example, its polyphenolic ether network and phenolic hydroxyl groups contribute to both high chemical stability and marked anti-tumor activities [12, 13].

Besides exhibiting structural variations, Bibenzyl compounds also display diverse therapeutic activities, including lipid regulation, anxiolysis, neuroprotection, and tumor suppression. Gigantol is considered as alkaloid,while dendrobine are considered as the main antioxidant compounds in D. officinale [12, 15].

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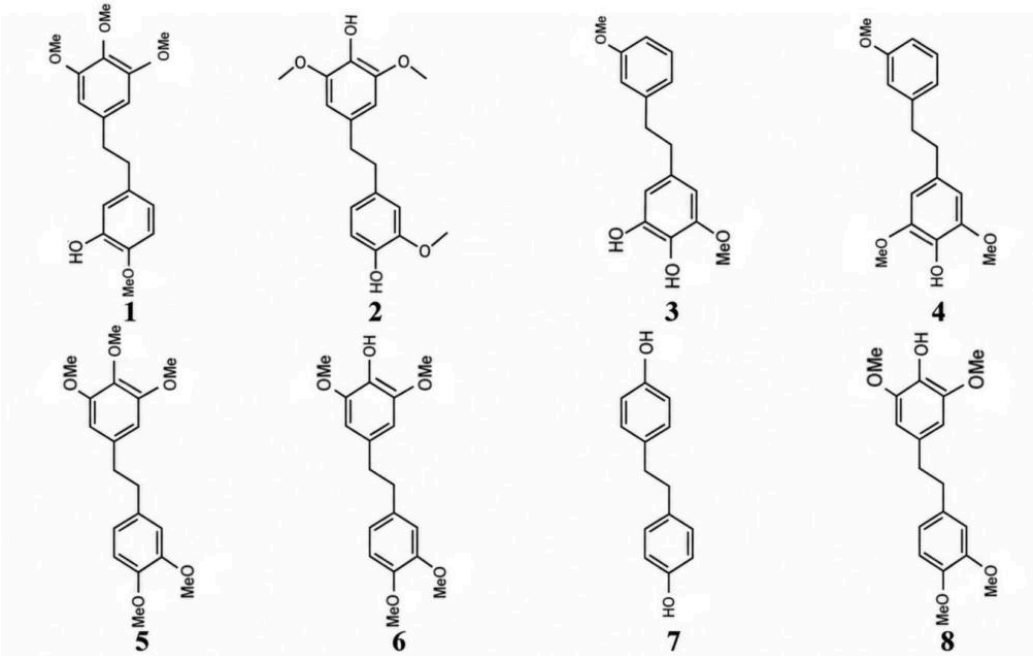

Figure 3. Chemical structures of major bibenzyl compounds

D.officinale has diverse flavonoids, including flavones, flavonols, dihydroflavones, dihydroflavonols, as well as aglycones with small amounts of isoflavones, chalcones, and dihydrochalcones [14]. It also includes a wide range of main compounds, such as apigenin, naringenin, eriodictyol, quercetin, taxifolin, isorhamnetin, hyperoside, and rutin [13].

Amino acids participate in protein synthesis and plants metabolism, serve as key bioactive constituents in Dendrobium species [16]. D. officinale harbors nearly all human essential amino acids, including key medicinal compounds such as glutamic acid, aspartic acid, arginine, glycine, and leucine, except tryptophan [5, 10, 14]. Aspartic and glutamic acids are special predominant species , which are thought to underline traditional therapeutic effects.This includes heat-clearing and anti-fatigue properties [14].Amino acids also contribute to the taste of D. officinale, with its sweet, light, and slightly salty flavor [4].

Dendrobium contains various mineral elements like P, K, Mg, Na, Zn, Mn, and Cu. These elements help regulate physiological functions in human bodies and indicate their food safety insurance [7].

3. Functional studies of the active components of dendrobium

Dendrobium polysaccharides has various advantages. It has significant efficacy, safe components, as well as its strong antioxidant activity, and with only a few side effects. Research demonstrates that D. officinale restores oxidative balance by enhancing antioxidant defenses and inhibiting the production of oxidative markers [17]. Polysaccharides with different molecular weights all show antioxidant activity, with free radical scavenging ability related to molecular weight and concentration. Notably, this activity follows a U-shape trend: with either low or high molecular weights, they exhibit stronger antioxidant effects, whereas those in the medium range show weaker

DOI: 10.54254/2753-8818/2027.38498

activity [18]. Vitro tests demonstrate that polysaccharides and glycoproteins can scavenge DPPH and hydroxyl radicals, and is able to exhibit metal-chelating activity in a concentration-dependent manner [19].

Alkaloids act as antioxidants primarily through the scavenging of hydroxyl radicals [7]. Flavonoids, flavonol and their aglycones are important contributors to antioxidant activity [15]. Most bibenzyl derivatives demonstrate notable antioxidant properties [4]. As gigantol is a representation of antioxidant capacity in D. officinale, it plays an important role in synergy with other active compounds, to name but a few, dendrobine [15].

In animal models of metabolic dysfunction, Dendrobium polysaccharides effectively lower high blood sugar. They help the body handle sugar better and make cells more responsive to insulin, which in turn reduces blood sugar, glycated proteins, and fasting insulin levels [15].DOP1 is the most effective element in D. officinale for reducing blood sugar [20]. Additionally, both crude polysaccharides and alcohol extracts can protect heart health. They can also help to improve metabolism by lowering top-number blood pressure and stabilizing blood sugar [19]. Alkaloids help lower blood sugar partly by keeping people's gut healthy. They balance the good and bad bacteria in the gut while regulating stomach acid and movement, which together build a stronger gut barrier [12]. Total alkaloids from D. nobile can enhance telomerase activity, helping to protect telomeres from damage and lower insulin resistance [6]. At the same time, flavonoids also help regulate blood sugar levels.

Polysaccharides are the main active components which execute systemic immunomodulatory functions [2]. Specifically, D. officinale enhances both innate and adaptive immunity across systemic levels, an effect driven in part by upregulating tumor necrosis factor and interleukin production [21].Polysaccharides are the key components that carry out full-body immune control [2]. In particular, D. officinale improves both natural and adaptive immune responses throughout the body, partly because it increases the production of tumor necrosis factor and interleukins [21].

In mice experiments, D. officinale polysaccharides stimulated splenic lymphocyte proliferation, developed both carbon particle clearance and spleen index [17]. Polysaccharides are essential for the innate immune system. They are able to activate autophagy, boost natural killer cell activity, and strengthen macrophage functions. The main components of Flavonoids are flavones and flavonols [22]. With unique structures and biological activities, alkaloids contribute greatly to immunomodulation [15]. As Figure 4 illustrates, D. huoshanense has immune-boosting effects as well as lipid-lowering and heart-protecting qualities [3].

Dendrobium polysaccharides can protect neurons from apoptosis and inflammatory damage, relieving nervous system diseases potentially [12]. Alkaloid components have neuroprotective properties and may help decrease Alzheimer's disease progression. Polysaccharides and dendrobine can help reduce brain cell damage and improve memory by adjusting cell pathways. However, current research on how they cross the blood-brain barrier and get absorbed by the body is still limited.

Mouse experiments show that by reducing Aβ1-40 and Aβ1-42 expression, total alkaloids from D. nobile can promote lysosomal acidification. They can also reduce neuronal and synaptic damage , as well as improving learning and memorizing functions [23]. Additionally, D. nobile alkaloids can affect spatial learning and memory by regulating Aβ25-35 expression, this can help to prevent neuronal apoptosis and synaptic loss [6].

D. officinale achieves its anti-tumor effects in several ways, such as boosting immune function, preventing cell division, encouraging cell death, offering antioxidants, and supporting chemotherapy treatment [21].. Polysaccharides, alkaloids, phenanthrenes, and bibenzyls can all fight against

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tumors because they can prevent cancer cells from dividing and encourage cell death. The water solubility of polysaccharides is an important condition for their biological activity [5]. Alkaloids from D. nobile can inhibit manganese-induced cytotoxicity by regulating PINK1/Parkin-mediated autophagic flux. Also, it can helps improving mitochondrial function [24, 22]. Two bibenzyl compounds have also been reported to possess anti-tumor activity [4].

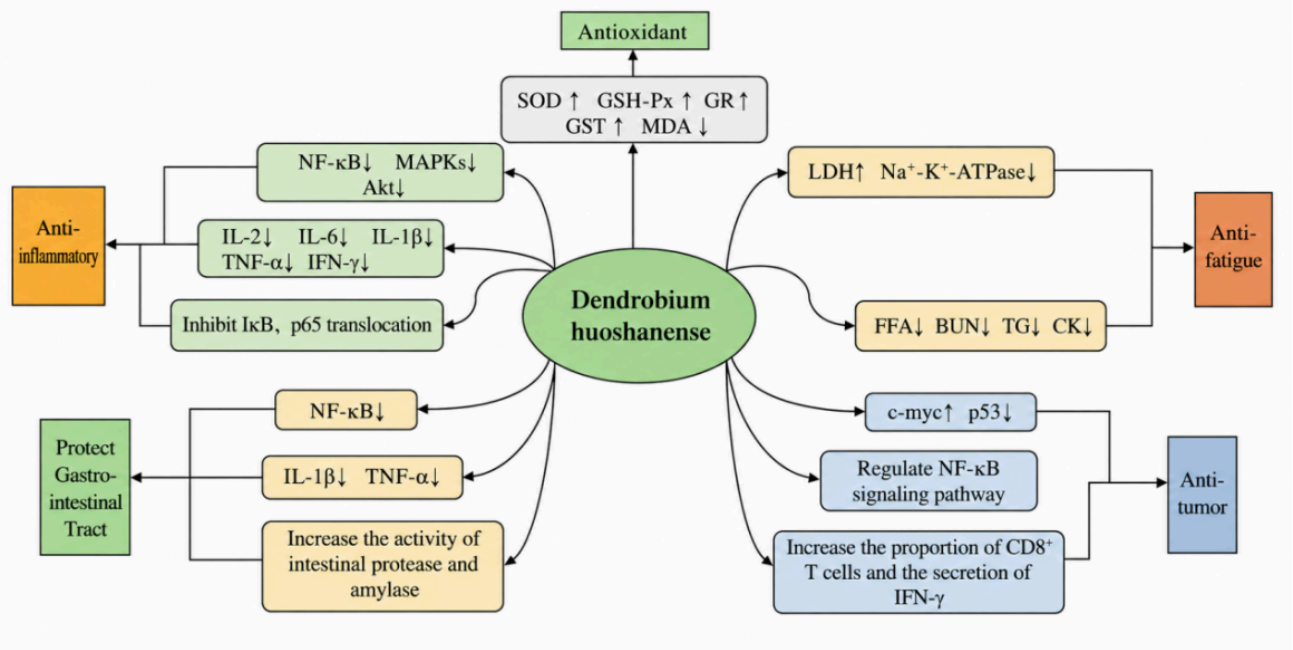

Figure 4. Pharmacological effects and related mechanisms of action of Dendrobium huoshanense

Experiments demonstrate that pretreatment with Dendrobium polysaccharides can increase mucus secretion and tight junction protein expression, thereby strengthening the gastric mucosal barrier and reducing inflammatory damage caused by alcohol [3].. Polysaccharides can inhibit inflammatory pathways such as NF-κB, MAPKs, PI3K/AKT, and JAK1/STAT3 to restore cytokine balance. Sesquiterpenes and octahydroindolizine-type alkaloids also play an significantly part in inhibiting NO and releasing cytokine [25]. For example, dendrobine from D. roseum can prevent macrophages from releasing too much nitric oxide, thereby offering protection against sudden lung damage [6].

Polysaccharides can lessen liver fibrosis by regulating cell pathways [25]. Meanwhile, sesquiterpenes reduce liver damage caused by alcohol, and total alkaloids from D. nobile lower fat accumulation in the liver, reducing the risk of fatty liver disease.Hepatoprotective actions of alkaloids rely heavily on Nrf2 pathway activation, which mitigates mitochondrial oxidative stress. Concurrently, these compounds help normalize lipid and bile acid homeostasis by suppressing excessive accumulation of triglycerides, cholesterol, and free bile acids [6]. D. huoshanense has significant hepatoprotective effects [3]. D. officinale polysaccharides can maintain intestinal environment stability by strengthening tight junctions between intestinal cells. It also plays an important role in inhibiting LPS-TLR4-NF-κB signaling pathway activation and preventing liver fibrosis as it can reduce apoptosis [19].

Dendrobium is essential in regulating the digestive system. D. officinale can increase 6-keto-PGF1α levels and at the same time, reduce TXB2, IL-8, and Gas levels. This can help to treat gastric heat syndrome [26]. Polysaccharides can regulate gut bacteria and short-chain fatty acids, which

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improves pathways related to metabolic and intestinal health [2]. Additionally, they reduce inflammation caused by overactive immune cells, restoring gut balance and relieving inflammatory bowel disease.In colorectal cancer, polysaccharides can inhibit autophagy by enhancing anti-tumor immune responses.

Experiments on mice demonstrate that D. officinale is rich in mucilage, which promotes gastric juice secretion and digestion. It helps repair damaged gut cells, encourages Lactobacillus growth, balances the gut microecology, and greatly improves constipation associated with spleen deficiency. Figure 5 shows the distribution of pharmacological activities of different plant components in Dendrobium [25].

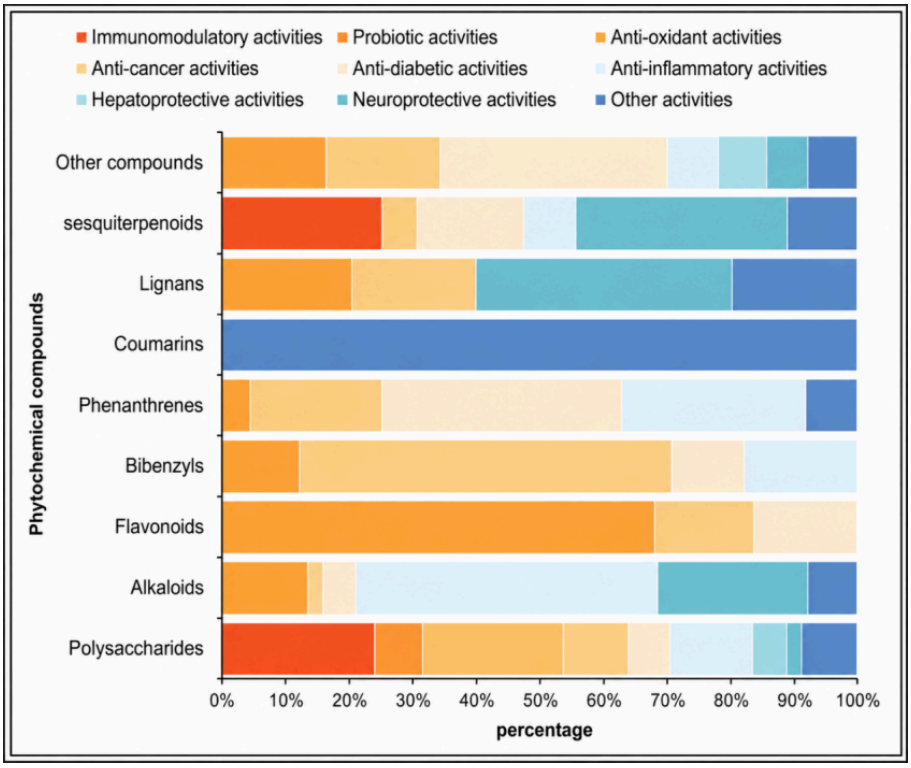

Figure 5. Distribution of pharmacological activities of different plant components in Dendrobium

4. Conclusion

Despite progress in isolation, structural analysis, and pharmacology, limitations remain. Component composition varies with species, cultivation, growth years, harvest time, and processing, causing inconsistent results and lacking unified quality standards. Most studies are in vitro or animal-based; clinical trials, safety evaluations, and mechanistic studies are insufficient. Multi-omics approaches (transcriptomics, proteomics, metabolomics, lipidomics) are needed for further validation.

Future research should integrate modern analytical technologies, multi-omics, glycomics, and AI-assisted analysis to elucidate fine structures, structure-activity relationships, and molecular mechanisms. Product development (medicines, foods, cosmetics), quality evaluation systems, and high-quality clinical studies should be strengthened to support functional food and natural medicine development, advancing the high-value utilization and industrialization of Dendrobium resources.

DOI: 10.54254/2753-8818/2027.38498

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