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Review

Structures, biological activities, and industrial applications of the polysaccharides from *Hericium erinaceus* (Lion's Mane) mushroom: A review

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ABSTRACT

Hericium erinaceus (Bull.) Pers., also known as Yamabushitake, Houtou and Lion's Mane, is capable of fortifying the spleen and nourishing the stomach, tranquilizing the mind, and fighting cancer. Over the past decade, it has been demonstrated that *H. erinaceus* polysaccharides possess various promising bioactivities, including antitumor and immunomodulation, anti-gastric ulcer, neuroprotection and neuroregeneration, anti-oxidation and hepatoprotection, anti-hyperlipidemia, anti-hyperglycemia, anti-fatigue and anti-aging. The purpose of the present review is to provide systematically reorganized information on extraction and purification, structure characteristics, biological activities, and industrial applications of *H. erinaceus* polysaccharides to support their therapeutic potentials and sanitarian functions.

Contents

1. Introduction

Hericium erinaceus (Bull.) Pers., also known as [1] Yamabushitake (Japanese), Houtou/猴头菇 (Chinese), Lion's Mane, Monkey's Mushroom, Bear's Head, Hog's Head Fungus, White Beard, Old Man's Beard, Pom Pom, and Bearded Tooth, used to belong to the

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Fig. 1. Fruiting bodies of *Hericium erinaceus* (Bull.) Pers. Photos taken by Henk Monster, in Holland (a); a CFDA approved drug named *H. erinaceus* extract granule (b); *H. erinaceus* in a growing room at Fungi Perfecti. Photos taken by Stuart Isett (c).

class Basidiomycetes, subclass Holobasidiomycetidae, order Hericiales, family Hericiaceae [2], while Index Fungorum [3] presents the currently adopted taxonomy of *Hericium erinaceus* (Bull.) Pers. as follows: Hericiaceae, Russulales, Incertae sedis, Agaricomycetes, Agaricomycotina, Basidiomycota, Fungi. *H. erinaceus* is mainly distributed through European countries and the southern states of America. However, there are no detailed descriptions and illustrations about the species from Asia, where its artificial cultivation has been developed in large quantities [4]. *H. erinaceus* which is considered as a saprotroph or weak parasite mostly occurs on dead wood, and sometimes on knotholes or cracks of living hardwoods [5–7]. The mature fruiting body is fleshy semi-spherical and whitish (Fig. 1a), and the color gradually becomes yellowish to brownish in age [8].

Studies on secondary metabolites have resulted in the isolation of an exceptionally large amount of structurally different and potentially bioactive components including erinacines, hericerins, steroids, alkaloids, and lactones [9]. Up to date, hericenones were reported only from the fruiting bodies of *H. erinaceus*, and erinacines were reported mainly from the mycelia derived from submerged cultures and were found in traces in fruiting bodies [10,11]. Every 100 g of dried *H. erinaceus* contains 61.3–77.5 g total sugar by proximate analysis [12–14], β-glucans, α-glucans and glucan-protein complexes are main representative polysaccharides [13]. In addition, it also has been reported that the total content of *H. erinaceus* polysaccharides in fruit bodies is higher than that in mycelium [15]. Up to date, a total of more than thirty-five polysaccharides have been isolated from *H. erinaceus*. Studies on pharmacological activities have revealed that *H. erinaceus* polysaccharides possess the potential to help prevent, alleviate, or treat major diseases including cancer, gastric ulcer, diabetes, hyperlipidemia, hepatic injury, and neurodegenerative diseases [16–20]. More recently, Khan [21] asserted the medical benefits of *H. erinaceus* polysaccharides by saying "This mushroom is rich in some physiologically important components, especially β-glucan polysaccharides, which are responsible for anti-cancer, immuno-modulating, hypolipidemic, antioxidant and neuro-protective activities of this mushroom". Therefore, *H. erinaceus* polysaccharides are very likely a kind of bioactive ingredients which could be proceeded to the development of pharmaceutical formulation. In facts, China Food and Drug Administration (CFDA) [22] has approved a large amount of patent health care products and medicines which all only contain *H. erinaceus* as the medicinal ingredient, including Hougu Yin, Hougu Pian, Houtoujun Pian, Weilexin Keli, Weilening Pian, Fufang Houtou Keli, Houtoujun Tiquwu Keli, etc. Some other patent products are reported from United States, Japan and South Korea [1]. It is worth mentioning that the efficacy of these products is capable of nourishing the stomach and harmonizing the middle energizer, and thus can be used for the treatment of epigastric pain caused by chronic superficial gastritis, gastric ulcer, or atrophic gastritis.

Up to date, no review concerning *H. erinaceus* polysaccharides is available. In this review, we intend to provide a comprehensive insight into the physiochemical and structural features and pharmacological effects of the polysaccharides obtained from *H. erinaceus* to provide knowledge to people for better utilization of polysaccharides, and to attract more scholars' attention on their anti-tumor and immunomodulatory, anti-gastric ulcer, hepatoprotective, hypoglycemic, hypolipidemic, neuroprotective and neuroregenerative activities. In addition, it is worth mentioning that the epithet "erinaceus" is still being misspelt as the grammatically incorrect "erinaceum" [1].

2. Extraction and purification

Over the past few years, methods about isolation and purification of potentially bioactive polysaccharides from *H. erinaceus* have gained much attention. The generally adopted polysaccharide extraction method is to stir the pulverized fruiting bodies in hot water for several hours, so it is very time-consuming. Microwave irradiation in water has an advantage for the extraction of polysaccharides from the fruiting body of *H. erinaceus* in terms of time duration. A study launched by Ookushi and colleagues [23] demonstrated that the extractability of microwave irradiation in water carried out at 140 °C for 5 mins was almost equivalent to that of using conventional external heating carried out at 100 °C for 6 h. The major polysaccharides obtained by microwave irradiation in water were β-D-glucans rich in $(1\rightarrow3)$ linkages, while polysaccharides obtained by traditional hot water extraction using conventional external heating were fucogalactans and β-D-glucans rich in $(1\rightarrow6)$ linkages, which was confirmed to be related to the removed heteropolysaccharides such as fucogalactan as depolymerized low molecular weight component [24].

Considering that the use of organic toxic solvents is not conducive to food safety, the limitation of organic toxic solvents and the integral fractionation of raw materials are desirable. A sequence of stages [25] including microwave hydrogravity, supercritical CO_2 extraction was used to obtain soluble fractions from *H. erinaceus*, and remaining solid phase were subjected either to enzyme assisted extraction or to non-isothermal autohydrolysis with water. The proposed green processes resulted in a dissolution of more than 40% of *H. erinaceus* [25]. Enzyme-assisted extraction possesses the advantage of being environmentally friendly, highly efficient, and easily operated owing to the relatively mild reaction conditions. Enzymes could effectively degrade the cell wall to favor the release of bioactive polysaccharides existing as a structural component in fungal cell walls. Response surface methodology and the Box-Behnken design based on single-factor and orthogonal experiments [26] were applied to optimize the enzyme-assisted extraction of polysaccharides from fruiting bodies of *H. erinaceus*, which resulted in the highest yield of *H. erinaceus* polysaccharides with a value of 13.46%.