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REVIEW

Biology, cultivation, and medicinal functions of the mushroom *Herichium erinaceum*

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Poznań, Poland* Corresponding author. Email: tenebrity@gmail.com**Abstract**

Herichium erinaceum (Bull.: Fr.) Pers. is an edible fungus of great significance in medicine. It is rarely found in Europe, in contrast, it is common in Japan and North America. Its fruitbodies have been well-known for hundreds of years in traditional Chinese medicine and cuisine. A cradle of *H. erinaceum* cultivation is Asia. In Eastern Europe is rare in natural habitats, but can be successfully cultivated. Both fruitbodies and mycelia are rich in active, health promoting substances. Tests of substances extracted from this mushroom carried out on animals and in vitro have given good results. They can be used in the treatment of cancer, hepatic disorders, Alzheimer's and Parkinson's diseases, wound healing. They improve cognitive abilities, support the nervous and immune systems. Promising results have been reported in clinical trials and case reports about the human treatment (e.g., recovery from schizophrenia, an improvement of the quality of sleep, alleviation of the menopause symptoms). The subject of this paper is to summarize information about the development of mycelium, the best conditions for cultivation of fruitbodies, bioactive substances and their use in medicine.

Keywords*Herichium erinaceum*; cultivation; medicine; bioactive compounds**Taxonomy, description, and occurrence**

Lion's mane mushroom, also called bearded tooth, *Herichium erinaceum* (Bull.: Fr.) Pers. used to belong to the class Basidiomycetes, subclass Holobasidiomycetidae, order Hericiales, family Hericiaceae [1], while Index Fungorum [2] presents the currently adopted taxonomy of *Herichium erinaceus* (Bull.) Pers. (described in 1979 by Persoon [3]) as follows: Basidiomycota, Agaricomycotina, Agaricomycetes, Incertae sedis, Russulales, Hericiaceae. Lion's mane mushroom is predominantly a saprophyte, but occasionally it may also be a weak parasite of trees [4]. This species is found on dead or dying deciduous trees belonging to genera *Quercus* sp., *Fagus* sp., *Acer* sp., *Juglans* sp., and *Ulmus* sp. [5–7]. It forms extensively branched fruitbodies, irregularly bulbous with a spiny hymenophore. The fruitbody is most frequently attached to the substrate sideways, with the base rounded or subglobose, protruding and unbranched [4]. Spores are ellipsoid, smooth to slightly roughened, around 5.5–7 × 4.5–5.5 μm [5].

Lion's mane mushroom is a rare species in Poland [4]. Five localities of *Herichium erinaceum* 'erinaceus' (Bull.: Fr.) Pers. have been reported from Poland by defining their hosts: *Carpinus* sp., *Fagus* sp., and *Quercus* sp. [8]. All species from the family

Hericiaceae are legally protected. In Poland, next to *H. erinaceum*, also *Hericium coralloides* (Scop.: Fr.) Pers. and *Hericium flagellum* (Scop.) Pers. (= *H. alpestre* Pers.) are found [8]. In Poland localities of lion's mane mushroom have been described from the Iński Landscape Park in Western Pomerania [9], as well as Oliwa Forests near Gdańsk, Hylaty Valley in the Bieszczady Mountains, and from the Lower Beskids region [10–12].

In the opinion of many authors lion's mane mushroom is common practically almost throughout the entire Northern Hemisphere, excluding tropical and polar regions [5,13–17]. *Hericium erinaceum* is rarely found in Europe [18]. It has been placed on the red list in several European countries; in contrast, it is common in Japan and North America.

In the late 1970's a new taxon was described, i.e., *Hericium erinaceum* subsp. *erinaceo abietis*. This taxon differed from the typical *H. erinaceum*, e.g., by morphological traits of the fruitbody, spore size and mycelium growth rate. Studies showed that the described subspecies was a sterile hybrid between *H. erinaceum* and *H. abietis* [19].

New possibilities for the classification of taxa of various ranks, e.g., strains and species of *Hericium* have been provided by the application of polymerase chain reaction (PCR) molecular identification. Using PCR Lu and his colleagues conducted taxonomic identification and determined phylogenetic affiliation of representatives of the family Hericiaceae with other Holobasidiomycetidae [20]. Studies showed that the family Hericiaceae is very closely related with different species of families Auriscalpiaceae, Echinodontaceae, Russulaceae, Schizophyllaceae and Stereaceae. The application of a molecular method, i.e., PCR, made it possible also to verify taxonomy. Thus, Canadian strains, previously known as *Hericium erinaceus*, were isolated as a new taxon in the rank of species – *Hericium americanum*. This species was described by Ginns in 1984 [21]. A significant role in the development of simple methods to determine taxonomic affiliation of lion's mane mushroom was played by a study by Adair's team [22]. Molecular PCR-RFLP techniques and their application made it possible to develop a rapid and simple method to detect the presence in wood of both *Hericium* sp. and other wood decomposing fungi already at the initial phase of their development [23].

Factors affecting mycelium growth in lion's mane mushroom

It was shown that growth of monokaryotic mycelia of lion's mane mushroom is typically slower than that of dikaryotic cultures. Only approx. 3% monokaryotic cultures yielded fruitbodies, which were always smaller in comparison to fruitbodies produced by dikaryotic mycelia. The dikaryotic mycelium of *Hericium* sp. differed considerably from the monokaryotic mycelium, e.g., by forming hyphae with clamp connections [24]. The monokaryotic mycelium formed 4 types of colonies, i.e., (i) thin, semi-airborne, showing a rapid growth comparable to that of a dikaryotic mycelium; (ii) compact, slower growing; (iii) thick and robust, characterized by very slow growth, and (iv) thin, with the slowest growth rate. The monokaryotic mycelium is capable of forming chlamydospores, spindle-shaped, of 6–8 × 8–10 μm. Chlamydospores remain viable for over 7 years and tolerate well storage under anaerobic conditions. The time required for chlamydospore germination ranges from 30 to 52 h, while germinability ranges from 32 to 54%, respectively [25].

Optimal sporulation conditions of *Hericium* sp. were defined [26]. Production of spores under natural conditions was greatest around noon, which was connected with an increase in temperature and a reduction of relative humidity (RH). In turn, sporulation under laboratory conditions at 85–95% RH increased with an increase in temperature to 24–27°C, while it stopped at 31–33°C. It was also found that at a temperature of 20°C spore production was greater at 30% RH than at 90% RH.

The effect of different factors on fungal spore germination was investigated in *Hericium* sp. An advantageous effect of growth regulators, e.g., 2,4-D and gibberellin, was observed on germination of lion's mane mushroom spores [27]. Studies were also conducted on the acceleration of spore germination using red and green laser

light. The application of low intensity light stimulated spore germination as well as the vegetative growth of mycelium on different substrates [28]. The use of argon and helium lasers in irradiation of mycelia resulted also in the acceleration of fructification, while it also increased the weight of a single fruitbody and the yield of fruitbodies by 36–51% [29].

Mycelium growth in *Hericium* sp. depends on different factors. In a study by optimal temperature for mycelium growth was 25°C [30]. The best mycelium growth on substrates was observed at pH 6. Most carbon sources, apart from lactose, promoted mycelium growth in *H. erinaceum*. In turn, alanine constituted the best source of nitrogen, while histidine was the least advantageous source. Investigations showed a stimulating effect of isoleucine chelate, applied at 100–200 ppm, on mycelium growth in *H. erinaceum* [31].

Mycelium growth rate in lion's mane mushroom in the substrate is closely connected with its enzymatic activity. *Hericium erinaceum* produces hydrolytic enzymes causing decomposition of cellulose, lignin, starch and proteins in the substrate. Mycelium growth rate in *Hericium* is correlated with the activity of β -amylase and protease [32]. Lion's mane mushroom is a species producing α -amylase, causing starch decomposition in the substrate [33]. Amylase isolated from fruitbodies of lion's mane mushroom showed optimal activity at pH 4.6 and temperature of 40°C [34]. *Hericium erinaceum* is a species with high activity of cellulase and laccase [35,36]. A correlation was found between the activity of laccase and the length of the development cycle in this fungus [37]. The higher the activity of released laccase, the shorter the growth period.

A high enzymatic activity of lion's mane mushroom facilitates its practical applications. Lion's mane mushroom is suitable for bioremediation, e.g., to treat sewage in the pulp and paper industry [38]. There is an application of composted spent mushroom substrate (SMS) from lion's mane mushroom culture for commercial scale production of such enzymes as α -amylase, cellulase, β -glucosidase, laccase and xylanase [39]. SMS may be applied as a readily available and cheap source of enzymes for bioremediation purposes [40].

Optimal temperature for mycelium growth in lion's mane mushroom is 21–24°C at substrate moisture content of 50 to 70% [5]. It was found that the optimal temperature for mycelium growth can be different and falls within the range of 25–30°C, while maximum temperature is 35°C [41]. For the fruiting period it is recommended the maintenance of constant temperature of 23°C [35]. Optimal pH of substrate may range from 5.8 to 6.2 [42]. Another study [43] showed that optimal temperature for Lion's mane mushroom yielding ranges from 10 to 24°C, while pH falls within a relatively broad range from 4 to 6, the recommended humidity is 85–95% and lighting intensity of 200–400 lx. Ranges of parameters, at which culture should be run, are close to the conditions found during mycelium growth. There was one more study reporting similar ranges of temperature and substrate moisture content as the previously mentioned authors, optimal pH also falls within a comparable range, as according to the authors it should be from 4 to 5 [44].

Cultivation of lion's mane mushroom

Cultivation of lion's mane mushroom may be extensive or intensive. The first one is applied on a wide scale in China. Wood logs or stumps are spawned with wood fragments overgrown with mycelium of lion's mane mushroom. Logs after spawning are placed in facilities where high humidity is maintained. Spawning takes place under natural, uncontrolled conditions, thus in this culture system fruitbodies are produced at various times, i.e., from several months up to a year after wood spawning. This method of lion's mane mushroom growing is very simple and does not require any considerable investment or specialist equipment. Its primary drawback is connected with the long period before mushroom yield may be harvested and high labor consumption [5].

Intensive cultivation methods need to be used order to obtain high yields of good quality. Intensive cultivation of lion's mane mushroom is typically run in bottles (Fig. 1,

Fig. 2) or bags (Fig. 3–Fig. 5). Substrates for culture need to be sterilized, thus bottles have to be made from heat resistant materials such as, e.g., polypropylene. In order to facilitate respiration of mycelium during spawning, bottles and bags used in culture have to be equipped with a filter, which will ensure gas exchange, while at the same time preventing penetration of microorganisms – bacteria or fungi, inside the bottles or bags. Cultivation in polypropylene bags is simpler and cheaper; however, fruitbodies growing from bags are typically smaller than those growing from bottles, where usually a single large fruitbody is produced [5,45,46]. Similarly as in the cultivation of other mushrooms, when growing lion's mane mushroom waste from agriculture, forestry, wood or food industries is used. Lion's mane mushroom may be cultivated, e.g., on sterilized sawdust supplemented with cereal bran [45,46].

Specialist literature sources present numerous recommendations concerning the composition of substrate for lion's mane mushroom culture [5,43,47]. Lion's mane mushroom may be grown, e.g., on wood coming from coniferous tree species, e.g., *Pinus taeda* and *Pinus ponderosa*. To obtain satisfactory yields chips produced from these trees have to be first spawned with mycelium of fungal species *Aureobasidium pullulans* var. *pullulans*, *Ceratocystis coerulea*, *C. pilifera* and *Ophiostoma piliferum*. These species, by degrading tar in wood of the above-mentioned species, make it suitable for lion's mane mushroom growing [48].

Substrate was developed and composed in 55% of corn cobs, 20% cotton chaff, 20% wheat bran, 3% corn meal, 1% gypsum and 1% sugar, which ensures very good mycelium growth and high yields of supreme fruitbodies [47]. Another substrate variant developed by Zhang contains 65% corn cobs, 10% cotton chaff, 20% wheat bran, 3% corn meal and 1% gypsum as well as 1% sugar. Similar materials for the substrate for lion's mane mushroom cultivation were used successfully: substrates formulated by that author were sterilized and contained cotton chaff (78%), wheat bran (20%), gypsum (1%) and sugar (1%) [45].

Lion's mane mushroom may be also grown on sterilized beech sawdust supplemented with 10% addition of wheat bran or 20% corn meal [49]. High yields were produced when sawdust was supplemented with wheat bran and corn meal added at 20% and 7% [50] and glucose added at 3% [51]. Suitability of waste from the textile industry to grow *Hericum erinaceum* was investigated [52]. Those authors obtained the highest yields using flax shives.

Rice straw of cultivars with high amounts of nutrients may be used as an additive enriching substrate [53]. In this case it should be added to the substrate at approximately 20% total substrate weight. Similarly as in the case of other mushrooms, the addition of enriching substances to the substrate accelerates the process of primordium formation and increases produced yields. Growing substrate may be supplemented with vegetable oils or fatty acids [54]. Among the seven substrate additives tested a soy meal proved to be the best [41]. The addition of sunflower husks as well as Mn and NH₄ to the cultivation substrate resulted in an accelerated mycelium growth and increased yields [55]. The highest yields can be obtained when sugarcane is used as an additive to growing substrate [35].

Chemical composition of *Hericum erinaceum* fruitbodies

Lion's mane mushroom has a relatively high nutritive value. Fruitbodies of lion's mane mushroom contain 57% carbohydrates, 3.52% fats, 7.81% fiber, 22.3% protein and 9.35% ash per dry matter (d.m.). Moreover, the following soluble sugars were also found: arabitol at 127.17 mg/g, glucose at 11.35 mg/g, mannitol at 12.98 mg/g, inositol at 1.43 mg/g and trehalose at 9.71 mg/g d.m. [56].

Detailed studies showed also contents of 14 amino acids in fruitbodies of this species. Among the detected amino acids the highest share was recorded for L-alanine at 2.43 mg/g d.m. and L-leucine at 2.38 mg/g d.m. The lowest contents were found for L-tryptophan at 0.10 mg/g d.m. and L-phenylalanine at 0.20 mg/g d.m. L-isoleucine and L-tyrosine were not detected [56]. Lion's mane mushroom contains considerable amounts of potassium and phosphorus, i.e., 254 and 109 mg/100 g dry matter, respectively [57]. The above-mentioned authors found also 19 amino acids and 32



Fig. 1 Cultures of *Hericium erinaceum* developed in the bottles. The expanding mycelium is clearly visible inside the bottles.



Fig. 2 Young fruitbodies of lion's mane mushroom are growing out of the bottle necks.



Fig. 3 General view of *Hericium erinaceum* culture in bags. Developing fruiting bodies growing out of bags with substrate.

aroma substances. Manganese, copper and zinc are found in *Hericium* in very low, trace amounts. Contents of heavy metals, i.e., arsenic, lead, copper, and cadmium, were higher in mycelium than in fruitbodies [58].

Analyses were also conducted on contents of aroma compounds in fruitbodies of lion's mane mushroom. The total content of volatile aroma compounds was determined in fruitbodies of lion's mane mushroom [59]. The dominant compound was 1-octen-3-ol, which accounted for 56–60% total content of aroma substances. In other study it was showed that the dominant compounds are 2-methyl-3-furanthiol, 2-ethylpyrazine and 2,6-diethylpyrazine [60]. Sixteen aroma substances were identified, containing nitrogen or sulfur, aldehydes, ketones, alcohols, and esters [61].

Biologically active substances in fruitbodies

Studies conducted in recent years have led to the isolation from lion's mane mushroom of several biologically active metabolites [62,63]. Both fruitbodies and mycelium of lion's mane mushroom contain health-promoting compounds. The cultivation on *H. erinaceum* may be optimized in order to obtain fruiting bodies reach in selected substances [64,65]. The most important groups of compounds include polysaccharides – for example: xylan (Fig. 6a), hericenones, and erinacines.

It was found that the total content of polysaccharides in fruitbodies of lion's mane mushroom exceeds considerably that in mycelium (26.63% and 18.71%, respectively) [66]. The qualitative and quantitative composition of polysaccharides in fruitbodies of lion's mane mushroom were investigated too [67,68]. There were the greatest content of arabinose, followed by glucose and ramnose in fruitbodies. The ratio of arabinose to glucose contents was 2.3 : 1. Total carbohydrates in mycelium of lion's mane mushroom were determined [69]. The authors also isolated 12 polysaccharides from the *H. erinaceum* extract and determined their molecular mass. New heteropolysaccharide (HEPF4) was isolated [70]. It was composed of D-galactose, L-fucose, D-glucose, and methylramnose.

The latest study indicates that the application of enzymatic extraction results in a 67.6% increase in the amount of polysaccharides in relation to hot water extraction



Fig. 4 Developing fruiting body of *Hericium erinaceum* cultivated in bag.

[71]. Thus obtained polysaccharide fraction was composed of mannose, glucose, xylose, and galactose at a ratio of 15.16 : 5.55 : 4.21 : 1. In another study stated that polysaccharides obtained from mycelium of lion's mane mushroom showed greater immunostimulatory activity after a 10% addition of ginseng extract to the growing medium [72].

Benzyl alcohol derivatives isolated from fruitbodies of lion's mane mushroom were named hericenones A, B, C, D, E, F, G, H [73–75]. Hericenones A and B showed strong cytotoxic properties towards HeLa cells. In the course of the investigations minimum concentrations were determined, at which these substances completely inhibited growth of HeLa cells. In turn, hericenones C, D and E stimulated the synthesis of the nerve growth factor (NGF). Activity of individual hericenones differed depending on the chain length and the presence of double bonds in fatty acids. The greatest capacity to stimulate NGF was found for hericenone E, having two double bonds in its chain [76].

Studies conducted by several other authors in fungal mycelium showed the presence of diterpenoid derivatives – for example diterpene (Fig. 6b), which were named erinacines A, B, C, E, F, G, H, I and P. Erinacines A, B, C, E, F and H showed strong activity inducing the

synthesis of the NGF both in vitro and in vivo [77–80]. Studies made it possible to determine the structure of the fatty acid coming from *Hericium erinaceum* [81]. This acid exhibited an inhibitory action towards HeLa cells. The safety of erinacine A application in animals was confirmed [82]. Erinacines, labeled J and K were isolated [83]. Detailed characteristic of diterpenoid compounds found in *Hericium* sp. was presented [84]. Those authors also showed the uniform distribution of terpenoid secondary metabolites in fruitbodies of *H. erinaceum*.

Other studies have led to the isolation of glycoside and 6 ergosterol derivatives from dried fruitbodies of lion's mane mushroom [85]. Another research on mycelium in liquid cultures led to the isolation of novel metabolites, which showed antibacterial and fungicidal properties, inhibiting growth of such microorganisms as *Bacillus subtilis*, *Saccharomyces cerevisiae*, *Verticillium dahliae* and *Aspergillus niger* [86]. From mycelium of *H. erinaceum* was isolated ergosterol peroxide, a cytotoxic steroidal derivative [87]. In next study new isohericerines were isolated from *H. erinaceum* – for instance hericerin A (Fig. 6c) [88]. After this research a new alkaloid with an anti-inflammatory feature named hericirine was isolated (Fig. 6d) [89] and a new glycoprotein compound was characterized: HEG-5 [90]. It has hemagglutinating and antineoplastic properties.

Lion's mane mushroom is one of the best known medicinal mushrooms, but new metabolites are still described, e.g., ten new isoindolin-1 ones, named erinacerins C–L were isolated from the solid culture of *H. erinaceum* [91].



Fig. 5 The fully developed mature fruiting body of *Hericium erinaceum* obtained from cultivation. In the background are visible an empty bag and the rest of substrate.

Medicinal functions of *Hericium erinaceum*

For centuries *H. erinaceum* has been used as an anti-inflammatory medicine, as well as an immune system booster. In China a medication Wei Le Xin Chong Ji is commercially available, which is used against ulcers, inflammations and neoplasms of the alimentary tract. Lion's mane mushroom is administered as tablets from dried and powdered fruitbodies. An advantageous action on hepatitis B patients was also shown for fresh fruitbodies of lion's mane mushroom. Thus, *H. erinaceum* has been a medication which use was justified by achievements and tradition of Chinese medicine. Its fruitbodies and preparations produced from them were treated as excellent medicinal material. However, there were no results of physiological and pharmaceutical tests adopted as a standard at the introduction of new medicinal preparations on the market in Europe and the USA [5,6,92–94]. Extracts (raw extract or its fractions) were thus subjected to standard tests in order to exclude their potential harmful effects and determine mechanisms of their bioactive action, in this way confirming their health-promoting properties.

Research conducted in recent years showed that lion's mane mushroom may have an advantageous effect in treatment of Alzheimer's disease [95] and leukemia, enhancing the mechanism of apoptosis of cancer cells (Tab. 1) [96]. Another

study showed effectiveness of an extract from fruitbodies of Lion's mane mushroom in controlling: cancer cells in human cell culture [97] and intestine cancer cells in mice [98]. Although most studies were conducted on animals, their results are considered to be very promising. The results of preliminary clinical trials also showed that the mushroom was effective in treatment of patients with dementia [99].

Experiments were conducted on antimutagenic properties of water and alcohol extracts produced from mycelium and fruitbodies of lion's mane mushroom [100]. In their study they used *Salmonella typhimurium* TA98 and different mutagenic compounds. These experiments showed antimutagenic action of the above-mentioned extracts, with a stronger effect of ethanol extract in comparison to water extracts. Extracts from mycelium showed a weaker action in relation to extracts produced from fruitbodies. It was also found that lion's mane mushroom contains lectins [101]. Lectins from *Herichium* sp. did not exhibit mitogenic properties [102].

Polysaccharides were isolated both from liquid medium, in which lion's mane mushroom was cultured [103], and from fruitbodies [104]. These compounds showed strong antineoplastic properties in studies conducted on mice. Polysaccharides caused an increase in the numbers of lymphocytes and macrophages and thus boosted the

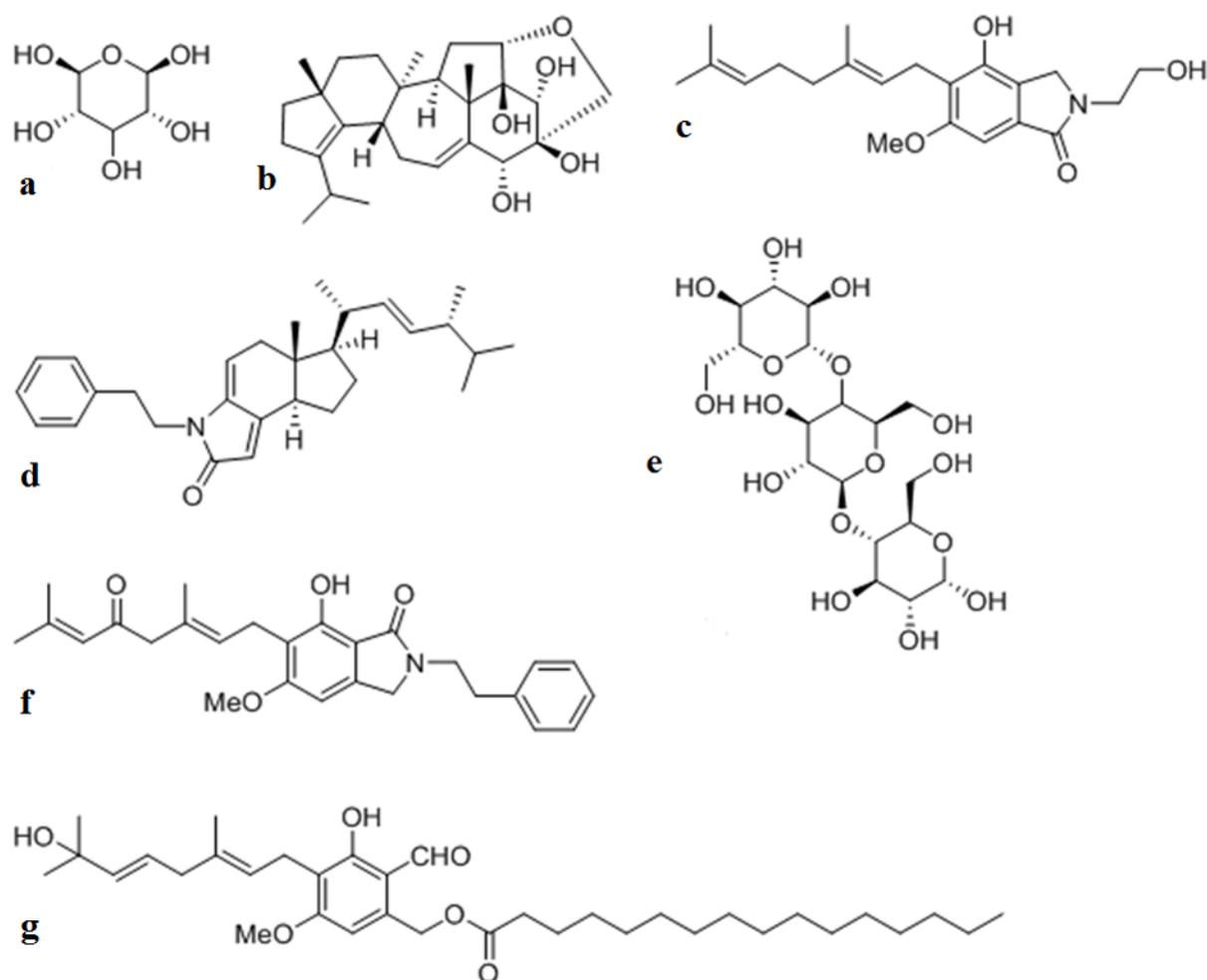


Fig. 6 The structures of compounds: xylan (a), diterpene (b), hericerin A (c), hericerin A (d), β -D-glucan (e), hericenone B (h), erinacene D (g).

immune system. They have significant anti fatigue activity [105]. The capacity to activate macrophages by water extracts from *H. erinaceum* was also confirmed [106,107]. HEP3 β -D-glucan (Fig. 6e) was characterized – obtained from fruitbodies of *H. erinaceum* [108]. A new heteropolysaccharide was isolated from fruitbodies of lion's mane mushroom [109]. It contains fucose, galactose and glucose as well as ramnose. The experiments on rats showed immunomodulatory properties of polysaccharides obtained from lion's mane mushroom, which was manifested in an increase in the secretion of cytokines IL-12, IFN- γ and IL-10 [110]. Polysaccharides obtained from *H. erinaceum* are capable of enhancing the activity of antioxidant enzymes in the skin, thus providing anti-ageing properties [111].

Ethanol extract from lion's mane mushroom counteracts neuron death [112]. Ethanol extracts from *H. erinaceum* contain the NGEF, which level is decreased in Alzheimer's patients, and this effect may prove helpful in treatment of this disease [95,113–115]. It can be used to control pain in diabetic neuropathy [116] and in treating Parkinson's disease [117]. Administration of lion's mane mushroom extracts enhances learning abilities and improves memory [118]. Extracts of lion's mane mushroom are appropriate in the prevention of dementia thanks to the enhancement of cognitive functions [119].

It was also found that methanol extracts from dried fruitbodies of lion's mane mushroom show antioxidant properties [120,121]. Antioxidant properties of methanol extracts are determined by the presence of polyphenols [122]. In studies on animals were showed antioxidant properties of polysaccharides obtained from *H. erinaceum* [123]. The product obtained by acetic acid fermentation using *H. erinaceum* as a substrate presented antioxidant properties [124].

In experiments on animals [125] was shown the protective effect of water extract of lion's mane mushroom in gastric ulcers. In another study [126] a protective effect on gastric mucosa was shown for different fractions obtained from ethanol extract from lion's mane mushroom. The polysaccharide complex obtained from lion's mane mushroom was effective against *Helicobacter pylori*, responsible for many gastric disorders [127]. The latest study [128] conducted in vitro confirmed the effectiveness of *H. erinaceum* extract against hepatic cancer cells HepG2 and Huh-7, colon cancer cells HT-29 and gastric cancer cells NCI-87. This indicates potential applications of lion's mane mushroom as a drug against gastrointestinal cancers.

There was a protective effect of methanol extract from lion's mane mushroom on liver cells [129]. Three polysaccharide fractions from lion's mane mushroom (HEP40, HEP60 and HEP80) has an applicability in the prevention of hepatic disorders [70]. In the opinion of many researchers, the potential hepatoprotective effect observed in vivo is connected with the antioxidant capacity confirmed in vitro. *Hericum erinaceum* has the capacity to induce apoptosis of human hepatocellular carcinoma cells [130]. *Hericum erinaceum* supplementation could restrain the hepatic damage caused by acute alcohol exposure [131].

Many researchers showed other health-promoting effects of lion's mane mushroom [132]. Female students who took drugs with its extracts declared the improvement of the quality of sleep [133]. Depression or anxiety were found much less frequently and were less intensive in menopausal women, who were administered powdered fruit-bodies of lion's mane mushroom in comparison to the group receiving placebo [134]. Drugs with their extracts are beneficial for treating primary cognitive deficits and negative symptoms of schizophrenia [135].

Other studies showed that water extracts promote healing process in open wounds and reduce the size and visibility of scars in scarified rats [136]. Another study [137] showed the effectiveness of water-soluble compounds isolated from lion's mane mushroom in the enhancement of immune response and in treatment of wounds. In turn, methanol extracts and substances they contained, i.e., D-threitol and D-arabinitol, as well as palmitic acid were capable of reducing blood lipid and glucose levels in examined rats [138].

Hericenone B (Fig. 6f) obtained from lion's mane mushroom is capable of inhibiting blood platelet aggregation [139]. *Hericum erinaceum* may regulate functions of

Tab. 1 Medicinal value of *Hericum erinaceum*.

Bioactive compounds	Activity	Treatment
Polysaccharides	Immunomodulatory	Cancers
	Anticancer	Gastrointestinal cancers (liver, gastric, colorectal), leukemia
	Anti-bacterial	<i>Helicobacter pylori</i> infection
	Gastroprotective	Ulcers, chronic gastritis
	Cholesterol and triglyceride lowering	Hyperlipidemia
	Hepatoprotective	Hepatic tissue damage
	Blood glucose lowering	Diabetes
Hericenones A–B	Cytotoxic	Cancers
	Anti-platelet aggregation	Vascular diseases, stroke, thrombosis
Hericenones C–H, erinacines A–I	Neuroprotective, neuroregenerative	Alzheimer's and Parkinson's diseases, dementia, depression
Hericinine	Reduction of pro-inflammatory mediators and cytokines	Inflammatory diseases
Poliphenols	Antioxidative	Anti-skin aging

the nervous, digestive, circulatory and immune systems of the organism, which would promote overall human health [140]. Substances from *H. erinaceum* may be used in the treatment and prevention of age-related diseases [141]. An addition of polysaccharides from lion's mane mushroom to feed for broiler chickens may lead to the production of meat with a reduced cholesterol level [142]. There were described some new compounds for example erinacene D (Fig. 6g) [143].

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