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MYCOCHEMICALS AND ANTIDIABETIC ACTIVITY OF LIGNOCOLOUS FUNGI – A CRITICAL REVIEW

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ABSTRACT

Plants and fungi have a potential resource of natural compounds used as medicine. They have attracted the attention of humans because of their wide variety of nutraceuticals and biochemicals with bioactivity. A wide variety of mycochemical compounds isolated from different species of lignicolous mushrooms have been identified and their bioactivities like Antimicrobial, Antibacterial, Antiviral, Anthelminthic, Antifungal, Antioxidant, Anticancerous, Antidiabetic, immune boosters, etc. have been reported by different mycologist around the world. The present paper mainly focuses on the antidiabetic mushrooms widely growing in the forest, and cultivation. The lignicolous macro-fungi have different varieties of mycochemical compounds with pharmacological importance; so present papers mainly deal with mycochemicals, antidiabetic activity, and factors affecting the concentration of the mycochemical compounds in wild and cultivated lignicolous macro-fungi.

Keywords: Lignicolous macro-fungi; biochemicals; antidiabetic; mycochemical concentration.

INTRODUCTION

Mycochemistry deals with the variety of chemical substances obtained from Fungi; such chemical substances are called mycochemicals. The mycochemstry deals with the isolation and identification of the molecular structure of the chemical compounds; their biosynthesis, metabolism, turnover, natural distribution, and biological properties [1]. Approximately 30,000 mushrooms are described worldwide [2], but only about 2,000 species are edible in around 20 species are cultivated commercially [3]. Mushrooms are used as nutrients in the human diet and consumed in a normal regular diet because of their taste, delicacy, and aroma [4]. Mushrooms were well known for their nutritional values; but recent studies mainly focus on the pharmaceutical resource used in traditional therapies which is started after the discovery of Penicillin [5]. The fungi became a resource of natural antibiotics and other bioactive compounds like mycochemicals.

Mushrooms are an abundant resource of a wide variety of useful mycochemical compounds which includes alkaloids, terpenoids, phenols, and steroids with documented bioactivities against diabetes, hypertension, hypercholesterolemia, and even cancer [6,7]. Mushroom cultivation has a long history in Eastern Asian countries like China (600 A.D.) with *Auricularia auricula-judae*or. During the 17thcentury in European countries, *Agaricus bisporus* cultivation was first achieved in France [8]. Mushroom cultivation was a good business in developing countries; where agricultural waste is utilized by mushroom growers as low-cost substances [9]. The most widely cultivated mushrooms throughout the world are *Agaricus bisporus* (button mushroom), followed by *Lentinus edodes* (shiitake), *Pleurotus* spp. (oyster mushrooms), *Auricularia auricula-judae* (wood ear mushroom), *Flammulina velutipes* (winter mushroom), and *Volvariella volvacea* (straw mushroom) [10]. The pominent best-selling mushrooms are *Grifola frondosa, Trametes versicolor, Lentinula edodes, Cordyceps sinensis, Schizophyllum commune, Hericium erinaceus*, and *Ganoderma lucidum* [11].

The wild and cultivated mushrooms were useful as dietary substances in some tribal cultures; they grew and consumed in their daily diet as supplementary food from the ages [12]. Nowadays, mushroom extracts are widely consumed by people; because of their health beneficial effects, which include the enhancement of immune system function and antitumor activity [13]. Mycologists confirmed that different mushroom extracts contain a diverse group of mycochemical bioactivity compounds like alkaloids, lectins, polyphenols polysaccharides, fibers, and proteins [13]. The wild and cultivated mushrooms were showed many characteristic pharmacological activities like Antitumor, Immunomodulatory, Antigenotoxic, Antioxidant, Anti-inflammatory, Hypocholesterolemic, Antihypertensive, Antiplatelet-aggregating, Antihyperglycemic, Antidiabetic, Antimicrobial, Antifungal, Anthelminthic, Antinematodal, Antiviral, Antimalarial, Antidandaruff, etc., [14,15].

LIGNICOLOUS MACRO-FUNGI

Lignicolous fungi are a diverse group of fungi in ecological and morphological aspects. These can decompose all wood polymers like lignin, cellulose, hemicelluloses, pectin, etc. by producing cell wall degrading enzymes. It also causes different types of diseases in woody trees growing in different forests of the world. It is estimated that there are approximately 1.5 million species of mushrooms in the world of which 70,000 species are characterized. About 10,000 of the known species are belongs to the lignicolous macrofungi; in which about 5000 species are edible and more than 1,800 species are considered medicinal [16]. These are nutritionally rich with primary and secondary metabolites and these are naturally growing on the plant parts like stem, leaves, branches, and roots of trees as well as other decaying wood materials [17,18]. Mycochemical compounds from these lignicolous macro-fungi bear tremendous importance to mankind, displaying a broad range of useful antibacterial, anti-cancerous, anti-inflammatory, antiviral, and pharmaceutical activities, at the same time bear less toxic effects [19].

MYCOCHEMICALS FROM LIGNICOLOUS FUNGI

***Agaricus bisporous* (J. E. Lange) Imbach:** The mycochemical studies in chloroform, ethyl acetate, methanol, ethanol, and aqueous extracts of *A. bisporous* showed the presence of alkaloids, phenols, flavonoids, tannins, anthraquinones, glycosides, lignin, sterols, volatile oils [87].

***Auricularia fuscosuccinea* (Mont.) Henn.:** Mycochemical analysis of *A. fuscosuccinea* water extract showed the occurrence of alkaloids, tannins glycosides, and absence of saponins and flavonoids respectively [88].

***Cantharellus cibarius* Fr.:** Bioactive primary and secondary metabolites were determined as indole groups, phenolic acids, flavonoids, organic acids, fatty acids, amino acids, and 5´nucleotides, carbohydrates, bioelements, vitamins, carotenoids, enzymes, sterols, and tocopherols [89,90].

***Coprinus comatus* (O. F. Müll.) Pers.:** Kalaw and Albinto [91] reported that alkaloids, flavonoids, saponins, and terpenoids are present in both fruiting bodies of *C. comatus*.

***Dacryopinax spathularia* (Schwein):** The macro-fungi contain Phenolics, Alkaloids, Flavonoids, Tannins, Saponins, and other mycochemical components. The *D. spathularia* contains comparatively more amount of Tannins, Alkaloid, and Saponins [92].

***Ganoderma*:** The genus *Ganoderma* (Ganodermataceae) has been extensively used as various therapeutic agents. Several species are widely studied and many of them are reported for potential bioactive compounds. The different mycologists who worked with *Ganoderma lucidum* belonging to Ganodermataceae reported several mycochemicals with bioactivity. It contains approximately 400 different Mycochemical bioactive compounds showing different kinds of pharmacological activities.

***Ganoderma applanatum* (Pers.) Pat:** Mycochemical analysis of sporophore extracts of *G. applanatum* prove the occurrence of alkaloids, carbohydrates, proteins, amino acids, phenolic compounds, flavonoids, tannins, terpenoids, diterpenoids, and Anthocyanin [84]. For the first time the phenols, alkaloids, and anthocyanins mycochemicals were reported from *G. applanatum* [22].

***Ganoderma brownii* (Murrill) Gilb.:** The chloroform and methanol extract of *G. brownii* showed the occurrence of carbohydrates, proteins, amino acids, alkaloids, phenols, flavonoids, glycosides, lipids, and steroids [86].

***Ganoderma lucidum* (Curtis) P. Karst:** Ethanol and methanol extract of *Ganoderma* was analyzed for bioactive compounds and it showed several triterpenoids and polysaccharides with different physiological effects. Some major compounds isolated from *G. lucidum* are sterols, lectins, and proteins [20]. Analysis of different water, methanol, ethanol, and 50% methanol extracts of *G. lucidum* indicated the occurrence of, carbohydrates, proteins, alkaloids phenols, flavones, tannins, terpenoids, diterpenoids, and anthocyanin [84]. Some important pharmacological properties of *G. lucidum* are the ability to reduce heart diseases, and cancer, and to stimulate the immune system [21]. Mycochemical analysis of *G. lucidum* a water extract showed the occurrence of alkaloids, saponins, tannins, and glycosides except for flavonoids [88]. In addition, Hoque et al. [93] also reported that extracts of *G. lucidum* have alkaloids, terpenoids, carbohydrates, tannins, flavonoids, and steroids.

***Ganoderma philippii* (Bres. & Henn. ex Sacc.) Bres.:** Qualitative mycochemical analysis of *G. philippii* extracts showed the occurrence of carbohydrates, proteins, amino acids, lipids, alkaloids, terpenoids, glycosides, phenols, saponins, steroids, except tannins and mucilage [85].

***Lentinus connatus* Berk.:** Ethanolic extract of edible mushroom, *L. conatus* showed the phenolic compounds in the highest quantity followed by flavonoids, ascorbic acid, β carotene, and lycopene bioactive mycochemicals respectively [94].

***Lentinus swartzii* Berk.:** The mycelia extract showed the presence of sugars, flavonoids, triterpenes, tannins, fatty acids, phenols, and essential oil; while the sporophore extract of *L. swartzii* have shown the same mycochemicals except for sugars and fatty acids [95].

***Phellinus*:** The genus *Phellinus* Quél. (Hymenochaetaceae) was a cosmopolitan polypore with many wood-rotting fungi. Some of the fungal species are reported for their pharmacological activity; so they are used in folk medicinal systems for ages. The wood-rotting fungi like *P. rimosus* have been used in the treatment of mumps disease by the Kerala tribes [23] and *P. durissimus* was used by the tribal peoples of Dang district in South Gujarat in their traditional medicinal practices [24]. These species are good sources of carbohydrates, proteins, fibers, fats, and minerals [25]. These are rich in various bioactive constituents like polysaccharides, alkaloids, tannins, flavonoids, phenols, terpenoids, and anthocyanins [26].

***Phellinus allardii (*Bres.) S. Ahmad:** The taxonomic identification and biochemical evaluation of the *P. allardii* sporophore were newly recorded from Dehradun and have shown the occurrence of carbohydrates, reducing sugars, proteins, amino acids, flavonoids, terpenoids, phenols, anthraquinone, tannins, glycosides, cardiac glycosides, and steroids, [25].

***Phellinus gilvus* (Schwein.) Pat.:** Mycochemical composition of hymenophores of *P. gilvus* hydro-alcoholic extract (70% ethanol) showed the presence of carbohydrates, reducing sugars, proteins, amino acids, alkaloids, flavonoids, terpenoids, phenols, tannins, anthraquinone, glycosides, cardiac glycosides and steroids [28].

***Phellinus noxious* (Corner) G. Cunningham:** The *P. noxious* extractions of ethanol and methanol were analyzed for mycochemical substances like alkaloids, tannins, flavonoids, phenols, terpenoids, diterpenoids, and anthocyanins and reported for the first time by Nagadesi et al. [22].

***Phellinus pachyphloeus* (Pat.) Pat:** Screening of mycochemical composition in the sporocarps of *P. pachyphloeus* (Pat.) Pat. collected from district Dehradun, Uttarakhand (India), shown the occurrence of carbohydrates, reducing sugars, proteins, amino acids, flavonoids, terpenoids, phenols, tannins, anthraquinone, glycosides, cardiac glycosides, and steroids with pharmaceutical and nutraceutical compounds [27].

***Phellinus torulosus* (Pers.) Bourdot & Galzin:** Mycochemical composition of hymenophore *P .torulosus* powder was extracted with 70% ethanol; showed the presence of carbohydrates, reducing sugars, proteins, amino acids, alkaloids, flavonoids, terpenoids, phenols, tannins, anthraquinone, glycosides, cardiac glycosides, and steroids, [28].

***Pleurotus cyctidiosus* O.K. Mill.:** Alkaloids, flavonoids, saponins, and terpenoids are present in the fruiting bodies of *P. cyctidiosus* [91].

***Pleurotus ostreatus* (Jacq. ex Fr.) P. Kumm:** The mature sporophore of *P. ostreatus* water extract showed the presence of proteins, reducing sugars and flavonoids in higher amounts, whereas carbohydrates and total phenols were increased in primordial extracts [96].

***Pyrrhoderma noxium* (Corner) L. W. Zhou & Y. C. Dai:** Sporophores of *Pyrrhoderma* was used as folk medicine from ancient times for the treatment of different human diseases [29]. *Pyrrhoderma* was showed the occurrence of different mycochemical, such as carbohydrates, polysaccharides, proteins, alkaloids, terpenoids, phenols, fatty acids, and steroids [24,22]. Several medicines prepared from *Pyrrhoderma* were used against different diseases throughout the world. The mycochemicals and proximate composition of *P. noxium* were done for standardization of powder. This showed that the method of extraction and type of solvent used in the preparation of extract influenced the occurrence of mycochemical compounds such as carbohydrates, alkaloids, flavonoids, terpenoids, phenols, and diterpenoids, tannins, and anthocyanin [30].

Phylloporia ribis **(Schumach.) Ryvarden:** Basidiocarps of edible *P. ribis are* used as a source of natural medicine in China [31]. The fruiting bodies of *P. ribis* have functional ingredients useful for curing pharyngitis, laryngitis, tonsillitis, and hyperglycemia [32]. For the first time, mycochemical bioactive compounds, proximate composition, and antifungal activity of *P. ribis* are reported from India [33].

Polyporus grammocephalus **Berk.:** *P. grammocephalus* (Polyporaceae) was a wood-rotting fungus that naturally grows on trunks of trees and wood logs. To establish the nutraceutical potentialities of this mushroom, the mycochemical composition, antioxidant property, and cytotoxic effect of its fruiting bodies was evaluated. The mycochemical analysis showed the occurrence of sugars, alkaloids, flavonoids, triterpenes, essential oils, phenols, fatty acids, anthraquinones, coumarins, anthrones, tannins, and. steroids, whereas terpenoids, cardiac glycosides, and saponins were not detected [34].

Russula cyanoxantha **(Schaeff.) Fr.:** The mycochemical analysis of *R. cyanoxantha* showed the occurrence of carbohydrates, alkaloids, flavonoids, terpenoids, phenols, saponins, tannin, glycoside, and steroids. The crude ethanol extracts of the *R. cyanoxantha* showed the presence of the highest mycochemicals compared to water and chloroform extracts [97].

Russula densifolia **Secr. ex. Gillet:** The qualitative mycochemical analysis showed the occurrence of carbohydrates, alkaloids, flavonoids, terpenoids, phenols, tannin, saponins, glycoside, and steroids in the *R. densifolia* mushroom [97].

Russula violepies **Quél.:** The qualitative analysis has shown the occurrence of carbohydrates, alkaloids, flavonoids, terpenoids, phenols, tannin, saponins, glycoside, and steroids in the *R. violepies* mushroom [97].

Terfezia boudieri **Chatin:** The chemical compounds like proteins, amino acids, fiber, minerals, and vitamins rich in *T. boudieri* fruiting the body. The quantitative estimate of nutritional compounds showed that *T. boudieri* has a preponderance of proteins and minerals (12.57 ± 0.13 and 15 ± 3g / 100g dry weight). The methanolic extract of the ascocarps showed high content of total phenols (44.68 ± 0.22 mg GAE / g), vitamin c, and carotenoids [98].

Termitomyces medius **R. Heim & Grasse:** Mycochemical analysis showed the total phenol content is higher than β–carotene and lycopene contents [99].

Termitomyces microcarpus **R. Heim:** Ethanolic extract of *T. microcarpus* showed the occurrence of mycochemicals in the following order total phenol> total flavonoids> ascorbic acid> β carotene> lycopene [100].

Trametes elegans **(Spreng.) Pat.:** The mycochemical screening revealed the presence of essential oil, fatty acids, anthraquinones, anthrones, tannins, flavonoids, phenols, alkaloids, steroids, and coumarins; However, terpenoids, cardiac glycosides, and saponins were not detected [101].

Trameteshirsuta **(Wulfen) Lloyd:** Mycochemical screening of *T. hirsuta* water extract showed the occurrence of alkaloids, flavonoids, saponins, and glycosides except for tannins [88].

Schizophyllum commune **Fries.:** The macrofungi contain Phenolics, Alkaloids, Flavonoids, Tannins, Saponins, and other mycochemical components. The *S. commune* has more amount of Phenolics and Flavonoids [92].

MYCOCHEMICALS WITH ANTIDIA-BETIC ACTIVITY

Many lignicolous macro-fungi are suitable for diabetic and heart patients because of their low starch and low cholesterol content in it. Several species of macro-fungi have been reported for the control of blood glucose levels and the modification of the course of diabetic complications [35,36,37]. These fungi contain mycochemicals with bioactivity that help in the proper functioning of the liver, pancreas, and other endocrinal glands and promote the formation of insulin and related hormones for healthy functioning of the body [38,39]. Macro-fungi contain polysaccharides such as beta-glucans which helps in the restoration of the function of pancreatic tissues by increased insulin output by β – cells, which leads to decreased blood glucose levels [40].

Agaricus bisporus (Lange) Imbach

Macro-fungi polysaccharides showed bioactivities like Antimicrobial, Antidiabetic, anti-cancerous, etc. So the *A. bisporus* of Thanjavur, Tamilnadu was tested for antidiabetic activity. The maximum inhibitory activity with 78.85% was observed at 2.0 mg mLG1; This confirms that polysaccharide substances show inhibitory activity against alfa-amylase-b [41].

Agaricus campestris **L.:** *A. campestris* grows fast and has a short shelf-life [42]. This macrofungus was used as medicine for the traditional treatment of diabetes. The administration of this macro-fungus through diet and drinking water can control the hyperglycemia of streptozotocin-diabetic mice [43].

Agaricus blazei **Murill:** *A. brasiliensis* sporophore was useful for health-promoting food in all organisms. Bioactivity studies on murine models and human volunteers were done to examine the immune-enhancing effects of the cultivated sporophore of *A. brasiliensis* KA21 (i.e. *A. blazei*). It has shown different activities like antitumor, leukocyte-enhancing, hepatopathy-alleviating, and endotoxin shock-alleviating effects in mice [44]. In humans, the % body fat, % visceral fat, cholesterol level, and glucose level in the blood were decreased and natural killer cell activity was increased [44]. Beta-glucans and oligosaccharides (AO) isolated from the *A. blazei* showed anti-hyperglycemic, anti-hyper-triglyceridemic, anti-hyper-cholesterolemic, and anti-arteriosclerotic activity; which indicates overall anti-diabetic activity for beta-glucans, whereas AO has twice the activity of beta-glucans concerning anti-diabetic activity in diabetic rats [45]. Further supplementation of *A. blaze* extracts has improved the insulin resistance among subjects with type 2 DM [46].

***Agrocybe aegerita* (V. Brig.) Singer:** It has a variety of bioactive compounds like indole derivatives cyclin, dan, and agrocybenine showing bioactivity like free radical scavenging activity, anticancer activity, and antifungal activity respectively [47]. A glucan and a heteroglycan are isolated from a sporophore hot-water extract of *A. cylindracea* and tested for antidiabetic activity. A glucan showed hypoglycemic activity in both normal and streptozotocin-induced diabetic mice by administering intraperitoneal [48].

***Auricularia auricular-judae* Bull.:** *A. auricula-judae* is popular in China as medicinal macrofungi use as food; a soup containing *A. auricula-judae*, chicken, pakchoi, and ginger was used for treating colds and fevers by reducing body heat [49]. The hypoglycemic activity of a water-soluble polysaccharide (FA) isolated from sporophore of *A. auricula-judae* was studied on genetically diabetic mice (KK-Ay); which showed that FA has a hypoglycemic effect on KK-Ay mice [50].

***Calvatia gigantean* (Batsch) Lloyd:** Methanol extract of *C. gigantea* was evaluated for antidiabetic activity as *in vitro* α-amylase assay test. The *in vitro* assay showed that the extract has antidiabetic activity with IC50 of 0.46 µg/mL compared to its DCM, butanol fractions, and acarbose IC50 5.3 µg/mL, 5.6 µg/mL, 45 µg/mL respectively [51].

***Coprinus comatus* O. F. Mull:** The *C. comatus* was edible before the gills turn into the black [52]. The species *C. comatus was* cultivated in China as food. It can use as hypoglycemic food for people with high blood glucose levels. The cultivated *C. comatus* was used for the hypoglycemic effect in Alloxan and adrenalin administered mice which showed that *C. comatus* was rich in vanadium and showed anti-hyperglycemic activity [53].

***Cordyceps sinensis* (Berk.) Sacc.:** *C. sinensis* (caterpillar fungus) is a medicinal mushroom in the traditional Chinese system of medicine [54]. Crude polysaccharides of *C. sinensis* were tested for hypoglycemic activity in both normal and streptozotocin-induced diabetic mice. It also showed a lowering of the glucose level in oral feeding mice [55]. A polysaccharide isolated from the cultured *C. sinensis* showed a hypoglycemic effect in genetically diabetic mice after intraperitoneal administration, whereas the plasma glucose concentration was quickly reduced in diabetic mice in normal and streptozotocin-induced conditions after intravenous administration [56]. The fruiting body of *Cordyceps* was used as food for diabetes because the diabetic rats had significantly lower weight gain and higher blood glucose response in the oral glucose tolerance test than the control rats [57]. Polysaccharides from *C. sinensis* (CSP-1) showed a significant decrease in blood glucose levels in both STZ and alloxan-induced diabetic mice [58].

Collybia confluens (Pers.: Fr.) Kummer

C. confluence exo-polymer (CCE) showed antidiabetic activity in streptozotocin (STZ)-induced diabetic rats. The CCE was extracted from the submerged mycelial culture of this fungi [59].

***Ganoderma applanatum* (Pers.) Pat:** *G. applanatum* exo-polymer (GAE) showed antidiabetic activity in streptozotocin (STZ)-induced diabetic rats. The GAE was extracted from submerged mycelial cultures of these fungi [59].

Ganoderma lucidum (Curtis) P. Karst

In the 4th century A.D., *G. lucidum* was used as an herb for long life in China. *Ganoderma* extract was used as a tonic in Chinese medicine because of its beneficial effect and nontoxic nature [60]. *G. lucidum* polysaccharides (Gl-PS) doses independently decreased the serum glucose levels after administration in mice. Gl-PS have hypoglycemic activity in normal mice; due to its insulin-releasing activity by facilitating Ca2+ inflow to the beta cells of the pancreas [61].

Grifola frondosa (Dicks.)

G. frondosa was very popular in Korea, China, and Japan as cultivated species commonly called maitake. The Maitake sporophore and its extracts can lower blood sugar due to the alpha-glucosidase inhibitor being present in it [62]. The alpha-glucan (MT-alpha-glucan) from the sporophore of maitake showed an antidiabetic effect in KK-Ay mice; which is proof that MT-alpha-glucan has anti-diabetic activity in KK-Ay mice. It also shows their effect on insulin receptors [63]. The animal, human model studies reveals that the sporophore of *G. frondosa* was showing an anti-diabetic effect [64].

Hericium erinaceus Bull.

H. erinaceus was commonly called Monkey Head Mushroom in China. Different *Hericium* sp. have shown physiological functions in humans, which include antioxidants, the regulation of lipid levels, and glucose levels in blood [65]. The hypoglycemic activity of methanol extract of *H. erinaceus* in streptozotocin-induced diabetic rats showed a decrease in blood glucose levels after feeding it [65].

Inonotus obliquus L.

I. obliquus is a white-rot fungus belonging to the Hymenochaetaceae family in the Basidiomycotina that grows on birch wood trees in colder northern climates [66]. In the 16th century, the lignicolous fungi *I. obliquus* was used as folk medicine in Russia and western Siberia [67]. The dry matter of *I. obliquus* culture showed anti-hyperglycemic, anti-lipid peroxidative, and antioxidant effects in alloxan-induced diabetic mice [68].

***Lentinus swartzii* Berk.:** Ethanolic extract of *L. swartzii* mycelium showed 81.98% of α-amylase inhibitory activity. The sporophore ethanolic extract showed 71.08% of α-amylase inhibitory activity [95].

***Pluteus cervinus* (Schäffer: Fr) P. Kumm.:** An increase in inhibition activity of a-amylase with an increase in the concentration of the extract. The IC50 value of the whole sample was 149.1 lL which implies that the IC50 value of the extraction is 7.455 lL/mL against the alfa-amylase enzyme. From previous reports, it is founded that the IC50 value of Acarbose was 427.33lL [102].

Pleurotus pulmonarius (Fr.) Quél.

P. pulmonarius was tested for its anti-diabetic activity in Wistar albino rats after inducing diabetes. Hot Water Extracts (HWE) and Acetone Extracts (AE) of *P. pulmonarius* mycelium were 55 mg/kilogram body weight orally administrated to STZ-NA and 200 and 400 mg/kg in diabetic Wistar albino rats for four weeks. The HWE of *P. pulmonarius* has shown a reduction in blood glucose levels. It also promotes a significant control of alpha-amylase enzyme in a concentration-dependent manner with 99.23% inhibition at 1000 mg/ml [69].

Poria cocos **F. A. Wolf**

P. cocos is a wood-decay fungus in terrestrial habitat used in traditional Chinese medicine [2]. *P. cocos* alone and in combination with other herbs used in treating diabetes [70]. The crude extract of *P. cocos* has dehydro-tumulosic acid, dehydro-trametenolic acid, and pachymic acid; which exhibited different levels of insulin sensitizer activity in streptozocin (STZ) treated mice [71]. The *P. cocos* sporophore extract and its triterpenes compound reduced the postprandial blood glucose levels in db/db mice via enhanced insulin sensitivity irrespective of PPAR-γ [71].

Russula **sp:** All extracts of the three *Russula* sp like *R. densifolia*, *R. cyanoxantha*, and *R. violepies* showed low to moderate alfa- amylase inhibition in a dose-dependent manner. The *R. violeipes* chloroform extract showed the highest alfa amylase inhibition activity with an IC50 value of 98 lg/ml; when compared to other mushroom extracts tested; whereas the standard drug, Acarbose showed an IC50 value of 146 lg/ml [97].

Tremella fuciformis **Berk.**

In Chinese cuisine, *T. fuciformis* is traditionally used in sweet dishes and medicine [72]. *T. fuciformis* of glucuronoxylomannan (AC) showed hypoglycemic activity in normal mice and streptozotocin-induced diabetic mice when sporophore was administered intraperitoneal [73]. The exopolysaccharides (EPS) produced by submerged mycelial culturing *T. fuciformis* showed anti-diabetic activities in ob/ob mice [24]. The EPS exhibits a considerable hypoglycemic effect and improved insulin sensitivity through regulating PPAR-gamma-mediated lipid metabolism [74].

FACTORS EFFECTING THE MYCOCHEMICAL COMPOUNDS IN LIGNICOLOUS FUNGI

The mycochemical compounds of *G. lucidium* are changing from one habitat to another. The effect of the extraction method and the solvent is influenced by the mycochemical compounds like total phenol content and total flavonoid content in lignicolous fungi. The proximate compound evaluation was used for the standardization of *G. lucidum* and *G. applanatum* powders [75]. The macro-fungal sporophores show morphological and physiological variations in mycochemical composition from batch to batch. The mycochemical profile of macro-fungi sporophore will show exactly supplementary ingredients and basic substrate composition as raw materials [76]. Macro-fungi show a degree of variation in size and age; which influences the specific biochemical composition [76]. The quality quantity of active substances varied from strain to strain, geological location, culture conditions, and the growth stage of the fungus [77]. The mushrooms are cultivated for mycelial biomass as a source of natural bioactive compounds. The submerged cultivation of mycelial biomass used for bioactive mycochemicals production in liquid media is less practiced. This cultivation technique has more benefits because macro-fungi can produce high biological compounds in a short incubation period. The different culture conditions like culture broth, pH, temperature, and shaking conditions were tested on wild and edible macro-fungi like *G. lucidum, P. cystidiosus, V. volvacea,* and *S. commune* for the production of mycelial biomass and bioactive lipids [78].

The maximum production of mycelial biomasses of *G. lucidum, P. cystidiosus, V. volvacea,* and *S. commune* was observed in Sabouraud dextrose broth at pH 7, 7.6, and 8, respectively, when incubated at 28°C and 30°C. The influence of different culture broths on the antioxidant and total phenolic contents of *L. tigrinus, L. sajor-caju, S. commune,* and *V. volvacea* was observed in broths were used for cultivation [79,80]. Upadhyay and Fritsche [81], high mycelial biomass production was shown under shaking conditions in case of *P. citrinopileus, P. florida,* and *P. sapidus;* whereas in *P. sajor-caju, C. comatus, K. mutabilis, L. edodes*, and *T. rutilans* the maximum biomass production was under static condition. When the shaking frequency was 50 rpm to 100 rpm there was an increase in the yield of *G. lucidum* mycelium, which indicates that better oxygen transfer was required in the broth medium for the mycelium growth [82]. The optimization of liquid culture conditions for the mycelial biomass of *Coprinopsis cinerea* reported for the active mycochemical components with important biological activities. The high yield of *C. cinerea* mycelial biomass was obtained when grown on potato sucrose broth with pH 7.5, incubated at 30°C, under alternating light, and dark conditions, and agitated at 70 rpm [83]. Mycochemical analysis showed that mycelial biomasses obtained in static and agitate conditions showed varying concentrations of saponins, flavonoids, cardiac glycosides, alkaloids, and terpenoids. Therefore, the liquid culture of *C. cinerea* was useful not only for mycelial biomass production but also for the natural resource of bioactive metabolites [83].

CONCLUSION

The lignicolous macro-fungi have demand for valuable resources of daily food, traditional medicine, and commercial income from ancient times to present. A wide variety of mycochemical compounds were isolated from different species of lignicolous mushrooms shown promising bioactivities like Antimicrobial, Antibacterial, Antiviral, Antihelmenthic, Antifungal, Antioxident, Anticancerous, Antidiabetic, immune boosters, etc. The present paper mainly focuses on the antidiabetic lignicolous macro-fungi widely growing in the forests, and its cultivation form. The Lignicolous macro-fungi have different varieties of mycochemical compounds likecarbohydrate, alkaloids, flavonoids, terpenoids, phenols, steroids, saponins, glycoside and tannin with pharmacological importance; so present papers mainly deal with mycochemicals, antidiabetic activity and factors affecting the mycochemical compounds concentration in wild and cultivated Lignicolous macro-fungi.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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