

BASIDIOMYCETOUS FUNGI: A NOVEL AGENT OF ANTIVIRAL AND ANTIBACTERIAL PROPERTIES

Abstract

Mushrooms (Basidiomycetous and ascomycetous fungi) are sources of several compounds such as secondary metabolites, lectin, lipids, peptides, proteins, and polysaccharides and are widely used for medicinal properties. The important aspect of medicinal mushrooms was evaluated by several researchers. The basidiomycetous fungi have antiviral, antibacterial, antifungal, antitherapeutic, antidiabetic, antitumor, antimicrobial, immunoregulative, anti-inflammatory and antioxidant properties. Because of this effect, it is used for anti-viral and antibacterial activity against human diseases. Also, some of the researchers found antiviral and antibacterial properties against plant diseases. The use of microbial origins for the management of plant diseases reduces the pollution in the environment and reduces the cost of input during cultural practices. This chapter delivers the importance of medicinal mushrooms against human and plant pathogens.

Keywords: Basidiomycetous Fungi, Antibacterial Properties, Plant Pathogens, Medicinal Mushrooms

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I. INTRODUCTION

Mushroom are freshly fruiting body belongs to class Basidiomycetes or Ascomycetes. It is typically grown above ground on soil or below ground as mycorrhizal fruiting bodies. It is a macrofungus with a characteristic fruiting body that is large enough to be seen with the unaided eye and plucked by hand. Mushrooms are frequently used as garnish in mythological tales, which are frequently linked to gnomes, fairies, and other fairytale characters.

Among 14,000 species of fungi, 1.5 million belong to the earth, generate large fruiting bodies, and are classified as mushrooms. The fruiting bodies have different parts, *viz.*, a stem (stipe), a cap (pileus), and gills (lamellae). The term "mushrooms" also refers to several other gilled fungi, some of which are Ascomycota and have stems or not. The small spores that are produced by these gills help the fungus spread.

Some mushrooms have a different morphology from the norm; these fungi are known by more particular names, including bolete, puffball, stinkhorn, and morel. Similarly, because of their resemblance to *Agaricus* or their order, Agaricales, gilled mushrooms are referred to as *Agaricus*.

Mushrooms have two growth phases, namely the vegetative phase (mycelia) and the reproductive phase (fruit bodies), and they are classified as basidiomycete and ascomycete. Their cell cycle includes the generation of sexual spores. In a unique structure known as the basidium (for Basidiomycetes) or ascus (for Ascomycetes), the fungal spores are located. The life cycle of the mushroom is divided into three distinct phases namely, the mushroom fruit bodies' vegetative growth, reproductive growth, and spore generation.

Based on their capacity to be consumed, mushrooms have been broadly divided into two categories: edible mushrooms, also known as mushrooms, and dangerous mushrooms, often known as toadstools. Due to their deliciousness and nutritional content, mushrooms used for food several decades. Low-calorie diets are made up for by edible mushrooms. Depending on the type of mushroom used, mushrooms typically include 15–33% crude protein, 0.7–7% crude fat, 57–73% carbs, and 348–390 Kcal of energy. Mushrooms' crude fat content is made up of lipids such sterols, mono, di, and triglycerides, as well as phospholipids.

Since they are high in protein, consist of essential quantity of fibre and necessary amino acids, and are low in fat but high in essential fatty acids, they have outstanding nutritional value. Additionally, edible mushrooms offer a substantial number of vitamins (B1, B2, B12, C, D, and E) that are nutritionally beneficial. In addition to being low in fat and high in protein and vitamins, mushrooms are also a great source of dietary fiber and several minerals and trace elements.

The nutritional worth and therapeutic benefits of mushrooms are recognized on a global scale. Their cultivation is a successful bioconversion technology that converts trash and wood into possibly valuable resources and could also play a significant role in sustainable agriculture and forestry. Despite having a good agroclimate, a large supply of agricultural waste, relatively inexpensive labor, and a diverse range of fungal species, India has seen only a modest increase in the cultivation of mushrooms. White button mushrooms

account for 73% of the total mushrooms produced in India, while oyster, paddy straw and milky mushrooms make up 16%, 7% and 3%, respectively, of the total. Indians consume even fewer than 100 g of mushrooms per person annually, which is quite low.

The top four mushrooms grown worldwide are *Agaricus bisporus*, *Lentinus edodes*, *Pleurotus* species, and *Flammulina velutipes*. Mushroom production is currently dominated by China, and this tendency is continuing. However, because of their medicinal, nutritional, and sensory properties, wild mushrooms are becoming more valuable. The best way to prevent disease, particularly oxidative stress, is to eat a healthy, balanced diet. In eastern medicine, the use of mushrooms for both illness prevention and therapy has a long history. Mushroom extracts are being offered as dietary supplements due to their advantages, particularly for enhancing immune system function and anticancer activity. *Ganoderma*, however, may have an antiviral antecedent.

In plains and tropical forests, *Phellinus rimosus* is widely distributed. In China, hot water extracts from the fruiting bodies of *Phellinus* spp. have been used to treat a variety of ailments and are said to rejuvenate the body and increase longevity. When tested *in vitro*, it was also discovered to scavenge O₂, OH, and nitric oxide radicals produced by free radicals (Ying, 1987).

Agaricus bisporus is also referred to as a button or table mushroom. It is widely grown all over the world, including in Europe and North America. When administered as a boiled or raw extract of *A. bisporus*, it has antioxidant capabilities and efficiently suppresses oxidative stress in *in vitro* studies (Jagadish *et al.*, 2009).

Pleurotus spp., also known as oyster mushrooms, are edible one. According to Jose *et al.* (2000, 2002), several *Pleurotus* species include antioxidants, anti-inflammatory chemicals, and anticancer chemicals. It has been discovered that the fruiting body of *P. florida* methanolic extract has OH radical-scavenging and lipid peroxidation-inhibiting properties. Proteins, lipids, phenolic compounds, and terpenes all play a role in the antibacterial capabilities of mushrooms.

1. Proteins: Mushrooms have bioactive proteins play a significant role in their functional components and are highly prized for their potential as medicinal ingredients. In addition to lectins, fungal immunomodulatory proteins, ribosome inactivating proteins, antimicrobial proteins, ribonucleases, and laccases, mushrooms also produce a vast number of other proteins and peptides with intriguing biological properties.

Lectins, which are non-immune proteins or glycoproteins that attach only to the carbohydrates on cell surfaces, are present in the majority of mushrooms. It is said to offer a wide range of medicinal effects, including immunomodulatory qualities and antitumoral, antiviral, antibacterial, and antifungal activity. Fungal immunomodulatory proteins, a new family of proteins identified from mushrooms, are adjuvants for tumor immunotherapy primarily because of their ability to inhibit tumor invasion and metastasis Xu *et al.*, 2002.

2. Lipids: Edible mushrooms contain polyunsaturated fatty acids, which can decrease blood cholesterol. Mushrooms have been found to lack trans-isomers of unsaturated fatty acids.

Ergosterol, a major sterol generated by edible mushrooms, has antioxidant properties. The prevention of cardiovascular illnesses depends on consuming a diet high in sterols. These antioxidants are biologically active and provide strong defense against cancer, heart disease, and degenerative disorders.

- 3. Phenolic Compounds:** Secondary metabolites are found in phenolic compounds, and they have a variety of physiological effects, including those that are anti-inflammatory, anti-microbial, anti-thrombotic, cardioprotective, and vasodilators. Because they function as reducing agents, free radical scavengers, singlet oxygen quenchers, or metal ion chelators, antioxidant activity plays a key role. Additionally, it offers defense against a number of degenerative conditions like cancer, cardiovascular disease, and brain malfunction. Mushrooms contain phenolic chemicals, which have significant antioxidant potential.

Ganoderma lucidum also known as ‘Ling-Zhi’ or ‘Reishi’. It is a basidiomycetous white rot fungus broadly used as therapeutic agent and traditional medicine. It consists of variety of high-molecular-weight polysaccharides and secondary metabolites (Zhou *et al.* 2007). Different polysaccharides and peptides *viz.*, ganoderans A, B, and C have been extracted from the fruiting body, spores, and mycelia of *Ganoderma*.

- 4. Terpenes:** Terpenes, which are naturally occurring chemicals made up of one or more isoprene C units, are present in a wide variety of plant species. It possesses inflammatory, tumor-suppressing, and hypolipidemic effects. A subclass of terpenes with a C-skeleton is called triterpenes. Triterpene synthesis is a common process in the growth and development of many plant species. Triterpenes, which are found in high concentrations in some plants' latex and resins, are thought to help some plants withstand illness. There have only been a few instances of triterpenes being successfully used as medicinal agents up to this point, despite the fact that hundreds of triterpenes have been isolated from diverse plants and the terpene class as a whole has been demonstrated to have numerous potentially advantageous properties (Table.1).

Table 1: Bioactive Compounds and their Activities of Basidiomycetes Fungus

Name of Mushroom	Active Principle/Constituents/ Extracts	Activity Reported
<i>Agaricus blazei</i>	1–3, 1–6-β-glucans	Anti-carcinogenic and mutagenic (Zivkovic <i>et al.</i> ,2017)
<i>Auricularia polytricha</i>	Methanolic extracts, dietary fiber	Antioxidant (Yip <i>et al.</i> , 1987), Hypocholesterolemic (Cheung, 1996)
<i>Boletus edulis</i>	Extracts of fruiting bodies	Antitumor (Lucas <i>et al.</i> , 1957)
<i>Cordyceps sinensis</i>	Cyclomannans and beta-mannans, and other polysaccharides	Anticancer (Zaidman <i>et al.</i> , 2005)
<i>Coriolus versicolor</i>	PSP (polysaccharide peptide) and PSK (also called Krestin)	Antitumor & antibacterial (Zaidman <i>et al.</i> , 2003)

<i>Fomitopsis officinalis</i>	Chlorinated coumarins 6-chloro-4-phenyl-2 H-chromen-2-one and ethyl 6-chloro-2-oxo-4-phenyl-2	Against <i>Mycobacterium tuberculosis</i> Anti- bacterial (Hwang <i>et al.</i> , 2013)
<i>Ganoderma lucidum</i>	Ganoderan A and B, glucans, Triterpenes, ganoderiol F , ganodermanontriol , ganoderic acids A, B, D, F, G, H, Z), ganosporeric acid A, ganopoly, the polysaccharide containing preparation.	Antioxidant and antitumor (Thekkuttuparambil <i>et al.</i> , 2007), antiviral (HIV-1) (El-Mekawy <i>et al.</i> , 1998), Antiallergic (Kohda <i>et al.</i> , 1985), Anti-inflammatory (Koyama <i>et al.</i> , 1997), antihepatotoxic (Hirotsani <i>et al.</i> , 1986)
<i>Grifola frondosa</i>	Rifolan and protein bound 1–3, 1–4-β-glucans, Grifron-D	Anti- oxidant property (Mau <i>et al.</i> , 2004)
<i>Hericium erinaceus</i>	Erinacin E	Antinociceptive (Saito <i>et al.</i> , 1998)
<i>Inonotus obliquus</i>	Hispolon and hispidin, phenolic compounds	Antiallergic (Ali <i>et al.</i> , 1996), Antiviral activity (Awadh <i>et al.</i> , 2003)
<i>Lentinula edodes</i>	Methanolic and water extracts, eritadenine, lentinan, oxalic acid, ethanolic mycelial extracts.	Antioxidant (Wang <i>et al.</i> , 1995 & 1996), Antimicrobial (Bender <i>et al.</i> , 2003)
<i>Polyporus umbellatus</i>	5α,8α-epidioxy-ergosta-6,22-dien-3-ol	Potentiators of ADP-induced platelet aggregation (Lu <i>et al.</i> , 1985)
<i>Schizophyllum commune</i>	Schizophyllan	Immunotherapy (Hazama <i>et al.</i> , 1995)
<i>Tremella fuciformis</i>	Acidic polysaccharide from the fruiting bodies	Hypoglycemic (Kiho <i>et al.</i> , 1994)

II. ANTIVIRAL ACTIVITY OF MUSHROOMS AGAINST HUMAN VIRUSES

The application of antibiotics does not easily manage or diminish viral illness. Therefore, a new approach to control is required to lessen the impact of viruses. A variety of chemicals found in medicinal mushrooms can directly block viral enzymes, inhibit the synthesis of viral nucleic acids, and help viruses enter mammalian cells. According to Brandt (2000), the presence of polysaccharides or other complex compounds in mushrooms has an antiviral and immune-modulating effect on people.

According to Mekkawy *et al.* (1998), the triterpenes (small molecular weight) ganoderiol F, ganodermanon triol, and ganoderic acid B in *Ganoderma lucidum* have antiviral properties against human immunodeficiency virus type 1 (HIV-1). Various other bioactive substances, including proteins, lignin derivatives, and polysaccharides, also have antiviral properties. The presence of polysaccharides and triterpenoid secondary metabolites in the mycelium and fruiting bodies of medicinal mushrooms is the primary cause of their antiviral activity (Chen *et al.*, 2012; Rincao *et al.*, 2012).

Nucleoside antibiotic, cordycepin are the secondary metabolites produced by the fungus *Cordyceps militaris*. Although *Ophiocordyceps sinensis* produces cordycepin, cordycepic acid, triterpenoids. *Lentinula edodes*, also referred to as shiitake mushrooms, has antiviral effects. Shiitake mushroom mycelial cultures were used to extract the water-soluble lignin antiviral component, which suppressed HIV replication *in vitro* and promoted bone marrow cell growth. The substance lentinan oversees the antiviral activity against HIV patients that has shown inhibitory activity. Additionally, the plaque reduction assay revealed that the glycoprotein from Shiitake spores had an antiviral component against the influenza virus.

III. ANTIVIRAL ACTIVITY OF MUSHROOMS AGAINST PLANT VIRUSES

Medicinal mushrooms are potential sources of secondary metabolites, proteins, and lipids. It has been widely used for medicinal purposes for human viruses. The lipids and secondary metabolites present in the mushroom have the potential to deplete or suppress the virion particles and multiplication of viruses in the plant cells. Some of the researchers reported the antiviral activity of basidiomycetous fungi against plant viruses.

Agaricus bisporus (white button mushroom), which consists of antiviral properties, *viz.*, pink quinone (β -L-glutaminy-3,4-benzoquinone) extracted in sporophores. It effectively prevents plant viral infections throughout the plant body. These extracts were treated with cowpea and pinto beans by mechanical inoculation. A high level of resistance and reduction of lesions numbers were observed in cowpea and pinto beans, respectively, against tobacco ringspot virus (TRSV) or tobacco mosaic virus (TMV) (Tavantzis and Smith, 1982). The aqueous extracts extracted from the fruiting bodies of *Agaricus brasiliensis* and *Lentinula edodes* resulted in antiviral activity against the cowpea aphid-borne mosaic virus infecting passion flowers (Di Piero *et al.*, 2010).

The "tinder conk" fungus, *Fomes fomentarius* polypore, is known for having antiviral properties. According to Lorenzen and Anke (1998), the *Fomes fomentarius* culture filtrates are extremely effective against the tobacco mosaic virus (TMV) when applied mechanically to tomato and bell pepper plants. Another important medicinal fungus is *Ganoderma lucidum* and *G. applanatum* reduced the tobacco mosaic virus infection up to 65–70% at the concentration of 1000 μ g/mL.

The fruiting bodies of *Agrocybe aegerita* consist of lectin (AAL), which possesses antiviral principles and is effective against tobacco mosaic virus (TMV), which is inoculated on *Nicotiana glutinosa* (Sun *et al.*, 2003). The development of local lesions on *Datura* plants against TMV was decreased by the application of polysaccharides at doses of 100–1000

g/mL derived from medicinal mushrooms. This is because polysaccharides include both neutral and acidic compounds (Kovalenko *et al.*, 2009).

IV. ANTIBACTERIAL ACTIVITY OF MUSHROOMS AGAINST HUMAN BACTERIA

Recently, the development of antibiotics has become increasingly important in the fight against bacterial illnesses. Antibiotics disrupt bacterial metabolism or weaken their structural integrity. Interferences with the production of the cell wall, changes in the permeability of the plasmatic membrane, disruptions of chromosomal replication, or interferences with protein synthesis are the basic mechanisms of action. As a result, different antibiotics can be used to control bacterial illnesses. Now a days, repeated usage of antibiotics causes resistance or a resurgence against antibiotics.

Considering this importance, the use of antibacterial compounds for fungus origin. A lot of secondary metabolites were present in basidiomycetous fungi, and they possess antibacterial compounds. And also, the extraction and use of secondary metabolites to control bacterial diseases reduces the cost. It might serve as a replacement for the creation of novel antibiotics.

According to numerous researchers (Barros *et al.*, 2007; Saddiqe *et al.*, 2010; Yu *et al.*, 2011; Li *et al.*, 2012; Wang *et al.*, 2012), macro basidiomycetous fungi have antibacterial action. The members of the mushroom orders *viz.*, Ganodermatales, Poriales, Agaricales, and Stereales were shown to have the highest levels of antibacterial capabilities. It may be effective against several bacterial diseases.

The antibacterial activity of numerous mushroom extracts has also been observed against gram-positive bacteria. Especially shiitake mushrooms (*Lentinula edodes*) were found to be effective against *Streptococcus* sp., *Actinomyces* sp., *Lactibacillus* sp., *Prevotella* sp., and *Porphyromonas*. According to Sheena *et al.* (2003), polyphenols, flavonoids, quinones, and terpenes were found in the methanol extracts of these fungi.

Auricularia and *Termitomyces* extracts were investigated for their antibacterial effects against *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Candida albicans*, and *Candida parapsilosis* by Gebreyohannes *et al.* in 2019. The antibacterial properties of *Termitomyces* and *Auricularia* were studied using chloroform, 70% ethanol, and hot water extracts. *Auricularia* extracts in chloroform and hot water displayed substantial antifungal effects, but *S. aureus* was most sensitive to *Termitomyces* extracts in 70% ethanol and hot water.

According to Lindequist *et al.* (2005), the fruiting bodies of both ascomycetous and basidiomycetous fungi contain antibacterial, antifungal, antiviral, antiparasitic, anticancer, immunomodulatory, insecticidal, and nematotoxic properties. According to Johansson *et al.* (2001), coprinol, which is efficient against gram-positive bacteria, is present in the culture filtrates of *Coprinus* spp. Acetone extract of *Ganoderma lucidum* (40µg/ml) was effective against *Klebsiella pneumoniae*.

V. ANTIBACTERIAL ACTIVITY OF MUSHROOMS AGAINST PLANT BACTERIA

Under both *in vitro* and *in vivo* conditions, the purified protein clitocybin from *C. geotropa* had an inhibitory impact on the bacterial wilt disease caused by *Ralstonia solanacearum* and also lessened the severity of the disease. These findings demonstrated the mushroom's antimicrobial properties. Additionally, the various extracts of *Clytocybe geotropa* inhibited *P. syringae* pv. *Syringae*, *R. solanacearum*, and *Erwinia carotovora* subsp. *Carotovora*. The *Coprinus* sp. extract of coprinol has shown inhibitory action against the majority of plant diseases.

Bacterial spots on tomatoes are caused by *Xanthomonas campestris* pv. *vesicatoria* (Xcv), and they cause devastating yield losses in production and productivity of tomatoes. The use of synthetic chemicals is costly and may also cause a resurgence against antibiotics. Hence, the best method is needed to manage the bacterial spot in tomatoes. Kaur et al. (2016) tested the *Lentinula edodes* (shiitake mushroom) against bacteria and found the antibacterial property. Foliar spray of culture filtrate of *L. edodes* substantially reduced the bacterial spot under *in vitro* conditions.

Kwak et al. (2015) screened different edible mushrooms like *Hericium erinaceus*, *Lentinula edodes*, *Grifola frondosa* and *Hypsizygus marmoreus* against *R. solanacearum* biovar 3. Among these edible mushrooms *Hericium erinaceus* showed the maximum inhibitory effect against *R. solanacearum*.

Chen and Huang, 2009 tested culture filtrates of five strains of *Clytocybe nuda* against pathogenic fungi like *Alternaria brassicola* and *Phytophthora capsica* and bacteria like *Ralstonia solanacearum*, *Xanthomonas campestris*, *X. oryzae* pv. *oryzae* and *Erwinia chrysanthemi*. All the five tested strains were effective against *Xanthomonas campestris* pv. *campestris* but not against *R. solanacearum*.

The Basidiomycetes fungi have an antibacterial effect, and they are easily isolated from mycelial extracts or basidiocarps of the fungus. Also, it is a cost-effective method. It may be useful for successful agriculture. Application of *L. edodes* into tomato plants inhibited the *C. michiganensis* subsp. *michiganensis* bacterial canker causing bacteria. Also induces systemic resistance in tomato plants (Silva et al., 2013). It induces the defense gene expressions, viz., peroxidase (POX), polyphenol oxidase (PPO), and chitinase (CHI) activities, at 1–72 h after spraying in the *L. edodes*-treated tomato plants. Also, the highest amount of lignin deposition was observed in the treated tomato plants. The results suggest that induced resistance was increased due to POX and PPO activities, improving lignification by CHI activity.

Bacteriolytic enzymes, lysozyme, and acid protease are found in *Ganoderma lucidum* and have antibacterial properties. Two basidiomycete mushrooms, *Ganoderma lucidum* and *Laetiporus sulphureus*, showed high antibacterial activity against *Agrobacterium rhizogenes*, *Agrobacterium tumefaciens*, *Erwinia carotovora* subsp. *carotovora*, *Pseudomonas syringae* pv. *syringae*, and *Xanthomonas campestris* pv. *campestris*.

The different extracts, like purified protein and clitocypin from *Clytocybe geotropa*, exhibited broad-spectrum antibacterial activity against *Ralstonia solanacearum*, *E. carotovora* subsp. *carotovora*, *P. syringae* pv. *syringae*, *X. campestris* pv. *vesicatoria*, and *Clavibacter michiganensis* subsp. *sepedonicus* by dual-culture assay.

VI. CONCLUSION

Mushrooms are widely used for consumption purpose despite of their role in various pharmaceuticals and industrial purposes. Mushrooms have excellent medicinal properties and can be a good alternative for the drugs that are consumed by humans. Mushrooms are also effective against several phytopathogenic bacteria and virus, although they are least exploited in this field. Mushrooms if exploited effectively can revolutionize our plant disease management system and act as an alternative to the toxic chemicals being used in the present situation.

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