**Basidiomycetous fungi: A novel agent of antiviral and antibacterial properties**

B. Sangeetha1\*, E. Adlin Pricilla Vasanthi, Patil Sneha Rashtrapal and R. Naveenkumar

Assistant Professor, School of Agricultural Sciences, Karunya Institute of Technology and Sciences, Coimbatore-641114.

\*Corresponding author: sangeethaagri5@gmail.com

**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.

1. **Introduction**

Mushroom is a fleshy, spore bearing fruiting body of a Basidiomycetous or Ascomycetous fungus, typically produced above the ground on soil or below the ground as mycorrhizal fruiting bodies. In broad sense, mushroom is a macro fungus with a distinctive fruiting body, which can be either epigeous or hypogeous and large enough to be seen with naked eye and to be picked by hand. Mythological stories are extensively garnished by mushrooms and is typically associated with gnomes, fairies, and other fairytale personages.

Approximately 14,000 species out of 1.5 million fungi present in the world produce fruiting bodies that are large enough to be considered as mushrooms. The structure of fruiting body consists of a stem (stipe) a cap (pileus) and gills (lamella/ lamellae) on the underside of the cap. Mushrooms also include a variety of other gilled fungi with or without stem and hence are described as fleshy fruiting bodies of some Ascomycota. These gills produce microscopic spores that aid in the dissemination of the fungus.

Certain mushrooms have a deviated morphology distinct from the standard morphology, such fungi are designated with more specific names such as bolete, puffball, stinkhorn, morel. Likewise, gilled mushrooms are referred to as agaricus due to their similarity to *Agaricus* or their order *Agaricales.*

Mushrooms belong to the class basidiomycete and ascomycete with a cell cycle including the formation of sexual spores and have two growth phases, i.e., the vegetative phase (mycelia) and the reproductive phase (fruit bodies). The fungal spores are in a special structure called the basidium (for Basidiomycetes) or the ascus (for Ascomycetes). The mushroom continues its life cycle in three key stages. viz., vegetative growth, reproductive growth, and spore production by fruit bodies of the mushrooms.

[Basidiomycetes](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/basidiomycetes) are considered to be a very interesting group of fungi given their exceptional adjustment abilities to accommodate themselves to the detrimental conditions of the environment where they constantly act as natural lignocellulose destroyers. Basidiomycetes possess the two types of extracellular enzymatic systems necessary to degrade the vegetal [biomass](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/biomass): (1) a hydrolytic system responsible for [polysaccharide](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/polysaccharide) degradation, consisting mainly of [xylanases](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/xylanase) and [cellulases](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/cellulase) and (2) a unique oxidative ligninolytic system, which degrades lignin and opens phenyl rings; this system comprises mainly [laccases](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/laccase), ligninases, and [peroxidases](https://www.sciencedirect.com/topics/biochemistry-genetics-and-molecular-biology/peroxidase).

Mushrooms have been widely categorized into two categories based on their consumption ability *i.e.* edible mushrooms that are referred as mushrooms and the poisonous mushrooms referred as toadstools. Mushrooms have been widely used as foods since a long time owing to their delicious and nutritious values. Edible mushrooms make up for of low-calorie diets. On a general note, mushrooms have ~15 – 33% crude protein, ~0.7 – 7% crude fat, ~57 – 73 % carbohydrates and ~ 348 to 390 Kcal of energy depending upon the mushroom used. Crude fat content of mushroom consists of lipids *viz.* mono, di, and triglycerides, sterols, phospholipids. They have a great nutritional value since they are quite rich in protein, with an important content of essential amino acids and fiber, poor fat but with excellent important fatty acids content. Moreover, edible mushrooms provide a nutritionally significant content of vitamins (B1, B2, B12, C, D, and E). Besides low fat and high protein and vitamin contents, mushrooms are rich sources of several minerals and trace elements, as well as dietary fibers. Mushrooms are found to be good source of vitamins especially thiamine [B1], riboflavin [B2] niacin, biotin, and ascorbic acid (vitamin C). Vitamin A and D are rarely found but certain species contain detectable amount of vitamin D when exposed to UV light. Thus, they could be an excellent source of many different nutraceuticals and might be used directly in human diet and to promote health for the synergistic effects of all the bioactive compounds present (Pereira, *et al*., 2012).

Even toxic mushrooms have found a place of relevance, because of the uniqueness of their compounds that evolved naturally as a protection against consumption.

Mushrooms are globally appreciated for their nutritional value and medicinal properties. Their cultivation is an effective bioconversion technology of transforming wastes and woods into potentially valuable resources and could also be an important part of sustainable agriculture and forestry. Although India has the advantage of favorable agroclimate, abundance of agrowastes, relatively low-cost labour, and a rich fungal biodiversity, it has witnessed a lukewarm response in growth of mushroom cultivation. Out of the total mushrooms produced in India, 73% are white button mushroom, 16% is oyster mushroom, 7% is paddy straw mushroom and 3% is milky mushroom. The per capita consumption of mushrooms in India is also very meager and is even less than 100 g per year.

The most cultivated mushroom worldwide is *Agaricus bisporus*, followed by *Lentinus edodes*, *Pleurotus* spp., and *Flammulina velutipes*. Mushrooms production continuously increases, China being the biggest producer around the world. However, wild mushrooms are becoming more important for their nutritional, sensory, and especially pharmacological characteristics.

A balanced diet is the supporting treatment for the prevention of illness and especially against oxidative stress. In this context, mushrooms have a long history of use in the oriental medicine to prevent and fight numerous diseases. Nowadays, mushroom extracts are commercialized as dietary supplements for their properties, mainly for the enhancement of immune function and antitumor activity.

Mushrooms have been reported to have medicinal properties. The edible class of mushrooms that shows potential medicinal and functional properties includes *Lentinus*, *Ganoderma*, *Auricularia,* *Hericium*, *Grifola*, *Flammulina*, *Pleurotus*, *and Tremella*. More than 100 medicinal functions are produced by mushrooms and fungi and the key medicinal uses are, antiallergic, immunomodulating, cardiovascular protector, anticholesterolemic, antiparasitic, antifungal, detoxification, and hepatoprotective effects; they also protect against tumor development and inflammatory processes. Numerous molecules synthesized by macrofungi are known to be bioactive, and these bioactive compounds found in fruit bodies, cultured mycelium, and cultured broth are polysaccharides, proteins, fats, minerals, glycosides, alkaloids, volatile oils, terpenoids, tocopherols, phenolics, flavonoids, carotenoids, folates, lectins, enzymes, ascorbic, and organic acids, in general. Polysaccharides are the most important for modern medicine and β-glucan is the best known and the most versatile metabolite with a wide spectrum of biological activity.

 The reported medicinal effects of mushrooms include anti-inflammatory effects, with anti-inflammatory compounds of mushrooms comprising a highly diversified group in terms of their chemical structure. They include polysaccharides, terpenoids, phenolic compounds, and many other low molecular weight molecules. Of late, mushrooms have emerged as wonderful source of nutraceuticals, antioxidants, anticancer, prebiotic, immunomodulating, anti-inflammatory, cardiovascular, antidiabetic, immunomodulatory, cardiovascular, liver protective, antifibrotic, antiviral, antioxidant, antitumor, and antimicrobial properties from the fruiting bodies, mycelia, and spores of the macrobasidiomycetes.

Some species producing conspicuous fruiting bodies have a long history of medicinal use. Bioactive compounds of the fungal genera which have had an important role in traditional medicine, such as *Ganoderma*, have been subject to extensive research. However, there is a broad number of other edible and medicinal species from different genera considered to be potential antiviral precursors.

*Phellinus rimosus*the species is mostly confined to plains and tropical forest. In Chinese medicine, the hot water extracts of fruiting body *of Phellinus* spp. have been reported to be used to cure many ailments and it is believed to refresh human body and promotes longevity. Various extracts of *Phellinus* spp. are found to scavenge O2, OH, and nitric oxide radicals generated from free radicals when studied *in vitro* (Ying, 1987).

*Agaricus bisporus* iscommonly known as button mushroom or table mushroom, *A. bisporus* is cultivated edible basidiomycetes found extensively in Europe and North America. It is perhaps one of the most cultivated species of mushroom across the world. Boiled as well as raw extract of *A. bisporus*, due to virtue of some antioxidants in it, effectively inhibited the oxidative crisis in in vitro experiments (Jagadish *et al*., 2009)*.*

*Pleurotus* speciesOyster mushroom/*Pleurotus* spp is an edible and extensively grown mushroom. Some species of *Pleurotus* are found to contain antioxidants, anti-inflammatory, and antitumor compounds (Jose *et al,* 2000, 2002). Methanolic extract from fruiting body of *P. florida* are found to have OH radical scavenging activity and lipid peroxidation inhibiting activities

Mushrooms could be an alternative source of new antimicrobial compounds, mainly secondary metabolites, such as terpenes, steroids, anthraquinones, benzoic acid derivatives, and quinolones, but also of some primary metabolites like oxalic acid, peptides, and proteins. *Lentinus edodes* is the most studied species and seems to have an antimicrobial action against both gram-positive and gram-negative bacteria. Proteins, lipids, phenolic compounds and terpenes present in mushrooms contribute for the antimicrobial activities.

###### **Proteins**

Bioactive proteins are an important part of functional components in mushrooms and also have great value for their pharmaceutical potential. Mushrooms produce a large number of proteins and peptides with interesting biological activities such as lectins, fungal immunomodulatory proteins, ribosome inactivating proteins, antimicrobial proteins, ribonucleases, and laccases.

Lectins are nonimmune proteins or glycoproteins binding specifically to cell surface carbohydrates and in the past few years many mushroom lectins have been discovered. They have many pharmaceutical activities and possess immunomodulatory properties, antitumoral, antiviral, antibacterial, and antifungal activity. Some of them exhibit highly potent antiproliferative activity toward some tumor cell lines (human leukemic T cells, hepatoma Hep G2 cells, and breast cancer MCF7 cells).

Fungal immunomodulatory proteins are a new family of bioactive proteins isolated from mushrooms, which have shown a potential application as adjuvants for tumour immunotherapy mainly due to their activity in suppressing tumour invasion and metastasis. Xu *et al.* 2002 published an extensive and comprehensive review about bioactive proteins in mushrooms.

1. **Lipids**

Polyunsaturated fatty acids are mostly contained in edible mushrooms; thus, they may contribute to the reduction of serum cholesterol. It is noteworthy that trans isomers of unsaturated fatty acids have not been detected in mushrooms. The major sterol produced by edible mushrooms is ergosterol, which shows antioxidant properties. It has been observed that a diet rich in sterols is important in the prevention of cardiovascular diseases.

Tocopherols, found in the lipidic fraction, are natural antioxidants because they act as free radical scavenging peroxyl components produced from different reactions. These antioxidants have high biological activity for protection against degenerative malfunctions, cancer, and cardiovascular diseases. Linoleic acid, an essential fatty acid to humans, takes part in a wide range of physiological functions; it reduces cardiovascular diseases, triglyceride levels, blood pressure, and arthritis.

###### **Phenolic Compounds**

Phenolic compounds are secondary metabolites possessing an aromatic ring with one or more hydroxyl groups, and their structures can be a simple phenolic molecule or a complex polymer. They exhibit a wide range of physiological properties, such as antiallergenic, antiatherogenic, anti-inflammatory, antimicrobial, antithrombotic, cardioprotective, and vasodilator effects. The main characteristic of this group of compounds has been related to its antioxidant activity because they act as reducing agents, free radical scavengers, singlet oxygen quenchers, or metal ion chelators.

Phenolic compounds provide protection against several degenerative disorders, including brain dysfunction, cancer, and cardiovascular diseases. This property is related to their capacity to act as antioxidants; they can scavenge free radicals and reactive oxygen species. The process of oxidation is essential for living organisms; it is necessary for the production of energy. However, the generation of free radicals has been implicated in several human diseases. The phenolic compounds in mushrooms show excellent antioxidant capacity.

Palacios et al. (2011) evaluated total phenolic and flavonoid contents in eight types of edible mushrooms (*Agaricus bisporus*, *Boletus edulis*, *Calocybe gambosa, Cantharellus cibarius, Craterellus cornucopioides, Hygrophorus marzuolus, Lactarius deliciosus*, and *Pleurotus ostreatus*). These authors concluded that mushrooms contain 1–6 mg of phenolics/g of dried mushroom and the flavonoid concentrations ranged between 0.9 and 3.0 mg/g of dried matter; the main flavonoids found were myricetin and catechin. *B. edulis* and *A. bisporus* presented the highest content of phenolic compounds, while *L. deliciosus*showed a high amount of flavonoids and *A. bisporus, P. ostreatus*, and *C. gambosa* presented low levels. Heleno et al. reported protocatechuic, p-hydroxybenzoic, p-coumaric and cinnamic acids in the phenolic fraction in five wild mushrooms from northeastern Portuga.

*Ganoderma lucidum* called ‘Ling-Zhi’ in Chinese, ‘Reishi’ in Japanese, and ‘Yeongji’ in Korean, is a basidiomycete white rot fungus that has been used as a health-preserving and therapeutic agent. Even today, *G. lucidum* is widely used in traditional medicine.

Fungi are remarkable for the variety of high-molecular-weight polysaccharide structures that they produce, and bioactive polyglycans are found in all parts of the mushroom. Polysaccharides represent structurally diverse biological macromolecules with wide-ranging physiochemical properties (Zhou et al. 2007). Various polysaccharides have been extracted from the fruit body, spores, and mycelia of lingzhi; they are produced by fungal mycelia cultured in fermenters and can differ in their sugar and peptide compositions and molecular weight (e.g., ganoderans A, B,

and C). *G. lucidum* polysaccharides (GL-PSs) are reported to exhibit a broad range of

bioactivities, including anti-inflammatory, hypoglycemic, antiulcer, antitumorigenic, and immunostimulant effects. Polysaccharides are normally obtained from the mushroom by extraction with hot water followed by precipitation with ethanol or methanol, but they can also be extracted with water and alkali. Structural analyses of GL-PSs indicate that glucose is their major sugar component (Bao et al. 2001; Wang et al. 2002).

However, GL-PSs are heteropolymers and can also contain xylose, mannose, galactose, and fucose in different conformations, including 1–3, 1–4, and 1–6-linked β and α-D (or L)- substitutions (Lee, Lee, and Lee 1999; Bao et al. 2002). Branching conformation and solubility characteristics are said to affect the antitumorigenic properties of these polysaccharides (Bao et al. 2001; Zhang, Zhang, and Chen 2001). The mushroom also consists of a matrix of the polysaccharide chitin, which is largely indigestible by the human body and is partly responsible for the physical hardness of the mushroom (Upton 2000). Numerous refined polysaccharide preparations extracted from *G. lucidum* are now marketed as over-the-counter treatment for chronic diseases, including cancer and liver disease (Gao *et al.* 2005).

Various bioactive peptidoglycans have also been isolated from *G. lucidum*, including *G. lucidum* proteoglycan (GLPG; with antiviral activity; Li, Liu and Zhao 2005), *G. lucidum* immunomodulating substance (GLIS; Ji et al. 2007), PGY (a water-soluble glycopeptide fractionated and purified from aqueous extracts of *G. lucidum* fruit bodies; Wu and Wang 2009), GL-PS peptide (GL-PP; Ho et al. 2007), and F3 (a fucose-containing glycoprotein fraction; Chien *et al*. 2004).

In addition, there was a marked synergistic effect when PBP from *G. lucidum* was used in tissue culture in conjunction with antiherpetic agents, acyclovir or vidarabine, and with IFN-α (Kim et al. 2000; Oh et al. 2000). Similar results were shown in HSV-1 and HSV-2 with a GLPG isolated from the mycelia of *G. lucidum* (Liu et al. 2004; Li, Liu, and Zhao 2005).

1. **Terpenes**

Terpenes are a class of naturally occurring compounds whose carbon skeletons are composed of one or more isoprene C units. Examples of terpenes are menthol (monoterpene) and β-carotene (tetraterpene). Many are alkenes, although some contain other functional groups, and many are cyclic. These compounds are widely distributed throughout the plant world and are found in prokaryotes as well as eukaryotes. Terpenes have also been found to have anti-inflammatory, antitumorigenic, and hypolipidemic activity. Terpenes in Ginkgo biloba, rosemary (Rosemarinus officinalis), and ginseng (Panax ginseng) are reported to contribute to the health-promoting effects of these herbs (Mahato and Sen 1997; Mashour, Lin, and Frishman 1998; Haralampidis, Trojanowska, and Osbourn 2002).

Triterpenes are a subclass of terpenes and have a basic skeleton of C. In general, triterpenoids have molecular weights ranging from 400 to 600 kDa and their chemical structure is complex and highly oxidized (Mahato and Sen 1997; Zhou et al. 2007). Many plant species synthesize triterpenes as part of their normal program of growth and development. Some plants contain large quantities of triterpenes in their latex and resins, and these are believed to contribute to disease resistance.

Although hundreds of triterpenes have been isolated from various plants and terpenes as a class have been shown to have many potentially beneficial effects, there is only limited application of triterpenes as successful therapeutic agents to date (Table.1). In general, very little is known about the enzymes and biochemical pathways involved in their biosynthesis.

**Table .1. Bioactive compounds and their activities of basidiomycetes fungus**

|  |  |  |
| --- | --- | --- |
| **Name of mushroom** | **Active principle/constituents/****extracts** | **Activity reported** |
| *Agaricus blazei*  | 1–3, 1–6-β-glucans | Anti-carcinogenic and mutagenic (Zivkovic *et* *al*.,2017) |
| *Auricularia polytricha*  | Methanolic extracts, dietary fiber | Antioxidant (Yip *et al*., 1987),Hypocholesterolemic (Cheung, 1996) |
| *Boletus edulis*  | Extracts of fruiting bodies | Antitumor (Lucas *et al*., 1957) |
| *Cordyceps sinensis*  | Cyclomannans and beta-mannans, and other polysaccharides | Anticancer (Zaidman *et al*., 2005) |
| *Coriolus versicolor*  | PSP (polysaccharide peptide) and PSK (also called Krestin) |  Antitumor & antibacterial (Zaidman *et al.,* 2003) |
| *Fomitopsis officinalis* |  Chlorinated coumarins 6-chloro-4-phenyl-2 H-chromen-2-one and ethyl 6-chloro-2-oxo-4-phenyl-2  | Against *Mycobacterium tuberculosis*Anti- bacterial(Hwang *et al* ., 2013) |
| *Ganoderma lucidum*  | 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. | Antioxidantand antitumor (Thekkuttuparambil *et al.*, 2007),antiviral (HIV-1) (El-Mekkawy *et al*., 1998),Antiallergic (Kohda *et al*., 1985), Anti-inflammatory (Koyama *et al*., 1997),antihepatotoxic (Hirotani *et al*., 1986) |
| *Grifola frondosa*  | Rifolan and protein bound 1–3, 1–4-β-glucans, Grifron-D | Anti- oxidant property (Mau *et al*., 2004) |
| *Hericium erinaceus*  | Erinacin E | Antinociceptive (Saito *et al*., 1998) |
| *Inonotus obliquus*  | Hispolon and hispidin,phenolic compounds | Antiallergic (Ali *et al*., 1996), Antiviral activity(Awadh *et al*., 2003) |
| *Lentinula edodes*  | Methanolic and water extracts, eritadenine, lentinan, oxalic acid, ethanolic mycelial extracts. | Antioxidant (Wang *et al*., 1995 & 1996), Antimicrobial (Bender *et al*., 2003) |
| *Polyporus umbellatus*  | 5α,8α-epidioxy-ergosta-6,22-dien-3-ol | Potentiators of ADP-induced platelet aggregation(Lu *et al*., 1985) |
| *Schizophyllum commune*  | Schizophyllan | Immunotherapy (Hazama *et al*., 1995) |
| *Tremella fuciformis*  | Acidic polysaccharide from the fruiting bodies | Hypoglycemic (Kiho *et al*., 1994) |

1. **Antiviral activity of mushrooms against human viruses**

Specific drugs are urgently needed for cure of viral diseases as they cannot be treated by common antibiotics. Antiviral effects are described not only for whole extracts of mushrooms but also for isolated compounds. They may act directly by inhibition of viral enzymes, synthesis of viral nucleic acids, or adsorption and uptake of viruses into mammalian cells. These direct antiviral effects are exhibited especially by smaller molecules. Indirect antiviral effects are the result of the immune-stimulating activity of polysaccharides or other complex molecules (Brandt, 2000).

Small molecular compounds with antiviral activities, several triterpenes from *Ganoderma lucidum* (i.e., ganoderiol F, ganodermanon triol, ganoderic acid B), are active as antiviral agents against human immunodeficiency virus type 1 (HIV-1) (Mekkawy *et al*., 1998).

Small-molecule fungal secondary metabolites have been a source of various drugs, and the same classes of secondary metabolites seem promising also against viruses. Other bioactive compounds with potential antiviral activities include high molecular weight compounds, such as polysaccharides, proteins and lignin-derivatives.

The antiviral activity of these mushrooms is associated mainly to the presence of polysaccharides in mycelium and fruiting bodies, and synthesis of triterpenoid secondary metabolites (Chen *et al*., 2012; Rincao *et al*., 2012). However, large number of other potentially bioactive compounds and/or genes involved in their synthesis has been reported (2003; Chen et al., 2012), indicating that the full potential of mushroom and medicinal fungi as a source of bioactive compounds remains only partially understood.

Brandt and Piraino, (2000) divided the antiviral compounds from fungi into two major classes: (i) those that act indirectly as biological response modifiers (usually from polysaccharide fractions) and (ii) those that act directly as viral inhibitors.

The fungus *Cordyceps militaris* is known to produce several secondary metabolites including a nucleoside antibiotic, cordycepin (Isaka *et al*., 2000). Medicinal properties of *O. sinensis* are attributed to cordycepin, cordycepic acid, triterpenoids and other active compounds (Rana, 2004).

Suzuki *et al*. (1990) characterized an antiviral water-soluble lignin in an extract of the mycelium of Shiitake mushrooms (*Lentinula edodes*) isolated from cultures grown on rice bran and sugar cane bagasse which limited HIV replication *in vitro* and stimulated the proliferation of bone-marrow cells. Clinical trials with lentinan in the treatment of HIV patients showed inhibitory activity.

The mushrooms *Lentinula edodes* (Berk.) Pegler (= *Lentinus edodes* (Berk.) Singer), known as shiitake, and *Agaricus brasiliensis* Wasser et al. (= *A*. *blazei* Murrill ss. Heinem.) are cultivated on a large scale in Brazil (Nascimento and Eira, 2007). These mushrooms are reported to produce antiviral substances against viruses that infect animals, such as *Human immunodeficiency virus* – HIV (Tochikura et al., 1988).

A glycoprotein isolated from Shiitake spores has been reported as an antiviral

substance which was effective against influenza. Effects against AIDS virus (HIV) have been found in some of the carcinostatic ß-D-glucans (lentinan and others) isolated from Shiitake and a water-soluble lignin-glycoprotein complex which was isolated from a mycelial autolysate of cultured Shiitake (Mizuno *et al*., 1995).

The most widely used methods for the initial screening of fungal extracts to evaluate their antiviral activity are the plaque reduction assay (Zhu et al., 2004; Faccin et al., 2007; Rincao et al., 2012), cytopathic effect (CPE) assay (Liu et al., 2004; Zhang et al., 2011) and immunofluorescence assay (Faccin et al., 2007)

1. **Antiviral activity of mushrooms against Plant viruses**

Medicinal mushrooms are good 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 antibacterial activity of basidiomycetous fungi against plant viruses.

Tavantzis and Smith, (1982) identified a pink quinone, β-L-glutaminyl-3,4-benzoquinone, present in sporophores of *Agaricus bisporus* as a potent systemic inhibitor of plant virus infections. A high level of resistance (98.5% or 81.5% reduction in members of lesions) has been observed when cowpea or pinto beans were mechanically inoculated with tobacco ringspot virus (TRSV) or tobacco mosaic virus (TMV).

Di Piero *et al*. (2010) proved that, the aqueous extracts of *Agaricus brasiliensis* and *Lentinula edodes* fruiting bodies showed antiviral activity against infections caused by cowpea aphid-borne mosaic virus on passion flower.

The filtrate from cultured biomass of the polypore *Fomes fomentarius*, “tinder conk,” is highly active against the mechanical transmission of tobacco mosaic virus (TMV), with an IC50 value of 10 μg/ mL, and it has similar effects against TMV infection on bell pepper and tomato plants was reported by Lorenzen and Anke, 1998.

Kovalenko *et al*. (2008) reported that *Ganoderma lucidum* and *G. applanatum* at a concentration of 1000 μg/mL inhibited 65–70% tobacco mosaic virus infection. A new lectin, named *Agrocybe aegerita* lectin (AAL), has been purified from the fruiting bodies of the edible mushroom *Agrocybe aegerita*. This AAL exhibited inhibitory effect on infection on *Nicotiana glutinosa* (Sun *et al*., 2003).

 Kovalenko *et al*. (2009) reported that the neutral and acid polysaccharides from mushrooms have different characteristics of antiphytoviral activity. Neutral polysaccharides expressed the inhibition on Datura plants the development of local lesions induced by TMV by 80% and 99.4% (in concentrations of 100– 1000 μg/mL).

Zehnder *et al*. (2000) conducted a greenhouse screening of PGPR for the potential to elicit ISR against *Cucumber mosaic virus* (CMV) on tomato. Each of the three strains selected from the 26 tested significantly reduced the mean percentage of symptomatic plants in each of five experiments with disease incidence ranging from 88 to 98% in the nonbacterized controls and 32 to 58% for the PGPR-treated plants. Murphy *et al*. (2000) reported that the various formulations of *B. amyloliquefaciens* IN937a, *B. subtilis* IN937b, and *B. pumilus* SE34 were tested in three field trials for the capacity to reduce incidence and severity of *Tomato mottle virus* (ToMoV) that is transmitted by whiteflies.

1. **Antibacterial activity of mushrooms against human bacteria**

The development of antibiotics has been one of the most important scientific achievements of the last seventy years. These compounds act in several ways, by interfering in metabolic processes or in the organism structures (Ozturk *et al*., 2011). The mechanism of action is mostly related with interferences in the synthesis of the cell wall, modification of plasmatic membrane permeability, interferences in chromosome replication, or in protein synthesis (Koch *et al*., 2003). The cell wall is responsible for the shape and rigidity of bacterial cells, acting as an osmotic barrier. The peptidoglycan content in the cell wall varies between 10% and 60% for gram-negative and gram-positive bacteria, respectively.

Secondary metabolites isolated from various Basidiomycetes have been known to show antibacterial properties. Basidiomycetes provide effective and low-cost products for human and plant disease control. Members of Ganodermatales, Poriales, Agaricales, and Stereales show potential antibacterial activity and these may become substitutes for developing new antibiotics. The effect of secondary metabolites of Basidiomycetes has been investigated mainly on human and animal pathogens.

There are numerous publications describing the antibacterial properties of secondary metabolites isolated from various higher Basidiomycetes (Barros et al., 2007; Saddiqe et al., 2010; Yu et al., 2011; Li et al., 2012; Wang et al., 2012). The antibacterial activity of some Basidiomycetes mushrooms provides efficient and low-cost methods for human and plant disease control. The highest antibacterial activity occurred among members of the Ganodermatales, Poriales, Agaricales, and Stereales, and these may constitute a good source for developing new antibiotics. But the effect of Basidiomycetes secondary metabolites has been investigated mainly on human and animal disease pathogens. Unfortunately, the publications describing antibacterial properties of isolated secondary metabolites of mushrooms on plant bacteria models are very limited. Despite this, several interesting publications have shown the potential of Basidiomycetes as valuable producers of substances that can be used successfully in the agricultural sector.

 Numerous mushroom extracts have been reported as having antimicrobial activity against gram-positive bacteria. Shiitake mushrooms were reported to be effective against *Streptococcus* sp., *Actinomyces* sp., *Lactibacillus* sp., *Prevotella* sp., *Porphyromonas* sp., of oral origin.

*Agaricus bisporus,* the most cultivated mushroom in the world, should be highlighted. Its methanolic extract revealed MIC = 5 μg/mL against *Bacillus subtilis,* even lower than the standard ampicillin (MIC = 12.5 μg/mL), and showed activity against *Bacillus cereus, Micrococcus luteus, Micrococcus flavus, Staphylococcus aureus,* and *Staphylococcus epidermidis*. Other *Agaricus* species have also demonstrated antimicrobial activity. *Agaricus bitorquis* and *Agaricus essettei* methanolic extracts showed an inhibitory effect upon all the tested gram-positive bacteria. *Agaricus silvicola* methanolic extract also revealed antimicrobial properties against *Bacillus cereus* (MIC = 5 μg/mL), *Bacillus subtilis* (MIC = 50 μg/mL), and against *Staphylococcus aureus* (MIC = 5 μg/mL), lower than the standard ampicillin (MIC = 6.25 μg/mL).

Antibacterial activity of the methanol extract of three polypore macrofungi *Phellinus rimosus*, *Ganoderma lucidum* and *Navesporus floccosa* were studied. The activity was evaluated by hole-plate diffusion and microtitre plate dilution methods using *Escherichia coli*, *Pseudomonas aeuroginosa*, *Staphylococcus aureus*, *Salmonella typhimurium*, and *Bacillus subtilis*. The methanol extract of *P. rimosus* and *N*. *floccose* showed activity against all the strains at a concentration of 800mg/well and 1mg/well, respectively*.* The methanol extract of *G. lucidum* showed activity against *E. coli*, *S. typhimurium* and *B. subtilis* at a concentration of 1mg/well. The minimum inhibitory concentration (MIC) of *P. rimosus* and *N. flocossa* were found to be 500mg/well and 1mg/well, respectively. The MIC of *G. lucidum* was also found to be 1mg/well. Chemical analysis of the methanol extracts of these fungi indicated the presence of polyphenols, flavonoids, quinones and terpenes (Sheena *et al*., 2003).

*Ganoderma lucidum,* is commonly known as Reishi. In Chinese folklore, fruit bodies of *Ganoderma* have been regarded as panaceae for all type of diseases. Our earlier investigations showed that extracts of the fruiting bodies of *G. lucidum* occurring in South India possessed profound antioxidant, antitumor, anti-inflammatory and antinociceptive properties.

Yamac and Bilgili in 2008 reported the antimicrobial activity of metabolites of certain mushrooms like *Amanita caesarae*. (Scop.: Fr.) Pers., *Armillaria mellea*. (Vahl) P. Kumm., *Chroogomphus rutilus*. (Schaeff.) O.K. Mill., *Clavariadelphus truncatus*. (Quel.) Donk., *Clitocybe geotropa*. (Bull.) Quél., *Ganoderma*. sp., *Ganoderma carnosum*. Pat., *Hydnum repandum*. L., *Hygrophorus agathosmus*. (Fr.) Fr., *Lenzites betulina*. (L.) Fr., *Lepista nuda*. (Bull.) Cooke, *Leucoagaricus pudicus*. (Bull.) Bon, *Paxillus involutus*. (Batsch) Fr., *Polyporus arcularius*. (Batsch) Fr., *Rhizopogon roseolus*. (Corda) Th.Fr., *Sarcodon imbricatus*. (L.) P. Karst., *Suillus collitinus*. (Fr.) O. Kuntze., *Trametes versicolor*. (L.) Lloyd, *Tricholoma auratum*. (Paulet) Gillet, and *Tricholoma fracticum*. (Britzelm.) Kreisel. The authors used the intercellular and extracellular metabolites of these mushrooms. The extracts of these mushrooms were tested against *Escherichia coli*. ATCC 25922, *Enterobacter aerogenes*. NRRL-B-3567, *Salmonella typhimurium*. NRRL-B-4440, *Pseudomonas aeruginosa*. ATCC 27853, *Staphylococcus aureus*. ATCC 25923, *Staphylococcus epidermidis*. NRRL-B-4377, *Bacillus subtilis*. NRRL-B-558, *Candida albicans*. ATCC 10259, and *Saccharomyces cerevisiae*. NRRL-Y-2034 by the disk diffusion and microdilution methods.  The authors reported that Chloroform extract of *Hygrophorus agathosmus* and dichloromethane extract of *Suillus collitinus* had the maximum antibacterial effect and antimicrobial effect against the bacteria and yeast.

Sum *et al.* (2018) isolated 12 basidiomycetes fungi from tropical forest of Kenya. The basidiomyectes fungi belonging to the genera *Inonotus, Fomitiporia, Ganoderma, Skeletocutis, Perenniporia, Favolaschia, Hexagonia, Polyporus, Antrodia and Echinochaete* were isolated and pure cultures were prepared. These fungi were extracted with ethyl acetate and screened for the antimicrobial activity against Bacillus subtilis, Escherichia coli, Mucor plumbeus and *Candida albicans*. Among the 12 fungal strains tested 9 exhibited enhanced antibacterial activity when compared to antifungal activity. *Skeletocutis nivea* and *Favolaschia calocera* crude extracts displayed the highest antibacterial activity against *B. subtilis* and antifungal activity against *C. tenuis.* The authors concluded the basidiomycetes to be a reservoir of antimicrobial fungal metabolites, that can be explored for drug resistance issues.

Erjavec *et al.* 2016 screened 94 different basidiomycete and ascomycete wild mushroom species against *Ralstonia solanacearum*. Among the 94 mushrooms tested 15 showed moderate to high antibacterial activity, 11 completely inhibited the bacteria while 4 showed partial inhibition.

Karaman *et al.* 2009 also reported the presence of antibacterial activity of organic extracts of 10 lignicolous mushrooms namely *Meripilus giganteus, Laetiporus sulphureus, Coriolus versicolor, Flammulina velutipes, Ganoderma lucidum, G. applanatum, Pleurotus ostreatus, Piptoporus betulinus, Panus tigrinus,* and *Fistulina hepatica* against 18 bacterial strains. It was the first report describing the antibacterial activity of *M. giganteus* and *P. tigrinus* against gram positive bacteria.

Gebreyohannes *et al.* (2019) tested the antimicrobial activity of *Auricularia and Termitomyces* extracts against *Escherichia coli, Klebsiella pneumoniae, Pseudomonas aeruginosa, Staphylococcus aureus, MRSA, Candida albicans, and Candida parapsilosis.* Choloroform, 70% ethanol and hot water extracts were used for understanding the antimicrobial activities of *Auricularia and Termitomyces.* Chloroform and hot water extracts of *Auricularia* had significant antifungal activities, while *S. aureus* exhibited maximum susceptibility towards the 70% ethanol and hot water extracts of *Termitomyces.*

Lindequist *et al.* (2005) reported that higher fungi *i.e.* the basidiomycteous and ascomyceteous fungi form compact tissue structures with fruiting bodies. These are called as mushrooms. These mushrooms have been reported to have antibacterial, antifungal, antiviral, antiparasitic, antitumor, immunomodulatory, insecticidal and nematotoxic activities. Johansson *et al.* (2001) screened culture filterate of *Coprinus* spp. against Gram positive bacteria. The authors reported a compound Coprinol from *Coprinus* spp. to be effective against the Gram positive bacteria.

Quereshi  *et al*., 2010 demonstrated the antibacterial activity of various solvent extracts (40µg/ml) of *Ganoderma lucidum* was tested against six species of bacteria: *Escherichia coli* (MTCC-443), *Staphylococcus aureus* (MTCC-737), *Klebsiella pneumoniae* (MTCC-2405), *Bacillus subtilis* (MTCC-1789) *Salmonella typhi* (MTCC-531) and *Pseudomonas aeruginosa* (MTCC-779). Acetone extract exhibited maximum antibacterial activity (31.60±0.10), while the most susceptible bacterium observed was *Klebsiella pneumoniae.*

The goal of research in the treatment of viral and bacterial infections is the discovery of agents that specifically inhibit viral and bacterial multiplication without affecting normal cells. The undesired side effects of antibiotics and antivirals and the appearance of resistant and mutant strains make the development of new agents an urgent requirement. This has led researchers to investigate the antibacterial and antiviral activity of medicinal plants and fungi (Wasser and Weis 1999; Zhong and Xiao 2009). Isolation of various water- and methanol-soluble, high-molecular weight PBPs from *G. lucidum* showed inhibitory effects on herpes simplex virus type 1 (HSV-1), herpes simplex virus type 2 (HSV-2), and vesicular stomatitis virus (VSV) New Jersey strain in a tissue culture system. Using the plaque reduction method, a significant inhibitory effect was seen at doses that showed no cytotoxicity (Eo et al. 1999; Oh et al. 2000).

Compounds having unique antiviral and antibacterial properties are prepared from medicinal mushroom mycelium, extracts and derivatives. The compositions are derived from *Fomitopsis, Piptoporus, Ganoderma, Inonotus, Trametes, Pleurotus*, and blends of medicinal mushroom species and are useful in preventing and treating viruses including Poxyiridae and Orthopox viruses, viruses including birds flu (H5N1), SARS and Hepatitis C (HCV), as well as infections from *Mycobacterium tuberculosis, Staphylococcus aureus* and *Escherichia coli.*

**V. Antibacterial activity of mushrooms against plant bacteria**

Erjave et al. (2016) reported that 15 Basidiomycetes extracts showed moderate to high antibacterial activities and three extracts regressed the disease as well as reduced the severity *in vitro* and *in vivo* against bacterial wilt disease caused by *Ralstonia solanacearum*. Extracts from *Clytocybe geotropa* showed broad range of inhibitionagainst *R.solanacearum*, *Erwiniacarotovora* subsp. *carotovora*, *P.syringae* pv. *syringae*, *X.campestris* pv. *vesicatoria*, and *Clavibacter michiganensis* subsp. *sepedonicus*. Purified protein, Clitocypin, from *C. geotropa* showed effective inhibition against *C. michiganensis* subsp. *Sepedonicus*. The fungicide strobilurin F 500 enhanced resistance of tobacco to the wild fire pathogen *Pseudomonas syringae* pv. *tabaci*. Coprinol, isolated from *Coprinus* sp., showed inhibitory activity against most of the plant pathogens.

Kaur *et al.* (2016) Bacterial spot of tomato (*Solanum lycopersicum*) caused by *Xanthomonas campestris pv. vesicatoria* (Xcv) is a devastating disease of tomato world-wide. In the southeastern United States, high summer temperatures and humidity are ideal conditions for this disease, resulting in defoliation, fruit spotting and a significant reduction in fruit yield. Current organic production practices restrict the use of synthetic chemicals for disease control; hence, there is a need for the development of new and effective biopesticides to mitigate plant diseases. Among several biological agents with potential for disease control, *Lentinula edodes* (shiitake mushroom) has been shown to have antibacterial properties. A controlled environment study was therefore conducted to validate *L. edodes* mycelia culture filtrate (Lemcf) foliar application to control bacterial spot of tomato using the cultivar Agriset 761. *Lentinula edodes* mycelia culture filtrate foliar spray significantly suppressed bacterial spot incidence in tomato foliage *in vitro* but was not effective *in vivo.* The phytotoxicity symptoms in Lemcf-treated tomato foliage were attributed to the presence of 422.78 mg of oxalic acid per milliliter of Lemcf (quantified by high-pressure liquid chromatography). Plant height and flowering were normal in Lemcf- treated plants. Additionally, Lemcf seed treatment did not adversely impact tomato germination but significantly enhanced the germination of marginal tomato seeds subjected to biotic stress (Xcv). The results suggest that after eliminating oxalic acid from Lemcf, the product may be a potential biopesticide for managing bacterial spot of tomato. Future greenhouse or field experiments should be conducted after eliminating oxalic acid from *L. edodes* culture filtrates.

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

Chen and Huang, 2009 screened the culture filtrates of five strains of *Ciltocybe* *nuda* against pathogenic fungi like *Alternaria brassicola* and *Phytophthora capsica* and bacteria like *Ralstonia solanacearum, Xanthomonas campestris* pv *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 antibacterial activity of some Basidiomycetes mushrooms provides efficient and low-cost methods for human and plant disease control. The highest antibacterial activity occurred among members of the Ganodermatales, Poriales, Agaricales, and Stereales, and these may constitute a good source for developing new antibiotics. But the effect of Basidiomycetes secondary metabolites has been investigated mainly on human and animal disease pathogens. Unfortunately, the publications describing antibacterial properties of isolated secondary metabolites of mushrooms on plant bacteria models are very limited. Despite this, several interesting publications have shown the potential of Basidiomycetes as valuable producers of substances that can be used successfully in the agricultural sector.

Silva et al. (2013) reported that *L. edodes* induced resistance in tomato against *C. michiganensis subsp. michiganensis.* Cavalcanti *et al*. 2016 studied the efficacy of controlling bacterial spot in susceptible tomato plants by using a natural product was compared to a commercial resistance inducer. Plants were sprayed with (a) acibenzolar-S-methyl, ASM [Bions 50WG (0.2 g l\_1)] and (b) a heterogeneous chitosan suspension (MCp) from *Crinipellis perniciosa* mycelium. Plants were challenged 4 d later with a virulent strain of *Xanthomonas vesicatoria*, under greenhouse conditions. In assessing disease, MCp-treated plants showed significant responses, reaching 87% of ASM protection performance against *X. vesicatoria leaf spot*. Tomato leaves exposed to MCp and ASM were assayed for pathogenesis-related enzymes, lignin deposition and soluble phenolic compounds. Induced resistance (IR) was evidenced by the enhancement of peroxidase (POX), polyphenol oxidase (PPO), and chitinase (CHI) activities at 1–72 h after spraying. These enzymes and phenylalanine ammonialyase (PAL) were also observed at 6, 9 and 12 d after spraying (DAS) interval. Treated and inoculated plants showed an increase in lignin deposition. The content of total soluble phenolic compounds decreased significantly by 9 and 12 DAS. The results suggest that (IR) was characterized by increased POX and PPO activities, improving lignification and, to a less extent, by CHI activity.

*Ganoderma lucidum*, a mushroom, is one of the most famous traditional Chinese medicinal herbs. One interesting aspect of its performance is antimicrobial effect due to the extracts derived from this mushroom which contain bacteriolytic enzyme, lysozyme and acid protease (Klaus & Miomir, 2007).

Two Basidiomycete mushrooms, *Ganoderma lucidum* and *Laetiporus sulphureus*, showed strong antibacterial activity against *Agrobacterium rhizogenes*, *Agrobacterium tumefaciens*, *Erwinia caroto­vora* subsp. *carotovora*, *Pseudomonas syringae* pv. *syringae*, and *Xanthomonas campestris* pv. *camp­estris* (Robles-Hernández, 2004).

Extracts from *Clytocybe geotropa* have shown the broadest range of inhibition against *Ralstonia solanacearum*, *E. carotovora* subsp. *carotovora*, *P. syringae* pv. *syringae*, *X. campestris* pv. *vesicatoria*, and *Clavibacter michiganensis* subsp. *sepedonicus*. Purified protein, clitocypinfrom *C. geotropa*, showed inhibition against *C. michiganensis* subsp. *sepedonicus* when tested on agar plates (Dreo et al., 2007).

**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.

**References:**

Barros, L., Baptista, P., Estevinho, L.M., Ferreira, I.C.F.R., 2007. Effect of fruiting body maturity stage on chemical composition and antimicrobial activity of *Lactarius* sp. mushrooms. *J. Agric. Food Chem. 55*: 8766–8771.

Barseghyan, G.S., Barazani, A. and Wasser, S.P., 2016. Medicinal mushrooms with anti-phytopathogenic and insecticidal properties. In *Mushroom Biotechnology*. 137-153. Academic Press.

Brandt, C.R. and Piraino, F., 2000. Mushroom antivirals. *Recent Research evelopments in Antimicrobial Agents and Chemotherapy*. *4*(1): 11-26.

Cavalcanti, F.R., Resende, M.L.V., Carvalho, C.P.S., Silveira, J.A.G. and Oliveira, J.T.A., 2007. An aqueous suspension of Crinipellis perniciosa mycelium activates tomato defence responses against Xanthomonas vesicatoria. *Crop Protection*, *26*(5).:.729-738.

Chen, S., Xu, J., Liu, C., Zhu, Y., Nelson, D. R., Zhou, S., et al. (2012).

Di Piero, R.M., Novaes, Q.S.D. and Pascholati, S.F., 2010. Effect of Agaricus brasiliensis and Lentinula edodes mushrooms on the infection of passionflower with Cowpea aphid-borne mosaic virus. *Brazilian Archives of Biology and Technology*, *53*(2):269-278.

Dreo, T., Želko, M., Scubic, J., Brzin, J., Ravnikar, M., 2007. Antibacterial activity of proteinaceous extracts of higher Basidiomycetes mushrooms against plant pathogenic bacteria. *Int. J. Med. Mushrooms 9 (3&4):* 226–227.

El-Mekkawy, S., Meselhy, M.R., Nakamura, N., Tezuka, Y., Hattori, M., Kakiuchi, N., Shimotohno, K., Kawahata, T. and Otake, T., 1998. Anti-HIV-1 and anti-HIV-1-protease substances from Ganoderma lucidum. *Phytochemistry*, *49*(6):1651-1657.

Faccin, L. C., Benati, F., Rincão, V. P., Mantovani, M. S., Soares, S. A., Gonzaga, fruiting bodies of Ganoderma lucidum (Fr.) Karst and its hypoglycemic
 potency on streptozotocin-induced type 2 diabetic mice. *J. Agric.Food Chem. 59:* 6492–6500.

Heleno, S. A., Barros, L., Martins, A., Queiroz, M. J. R., Santos-Buelga, C., & Ferreira, I. C. (2012). Phenolic, polysaccharidic, and lipidic fractions of mushrooms from Northeastern Portugal: chemical compounds with antioxidant properties. *Journal of Agricultural and Food Chemistry*, *60*(18), 4634-4640.

Hernandez, L.R. 2004. *Novel antimicrobial activities of Ganoderma lucidum and Laetiporus sulphureus for agriculture*. University of Idaho.Genome sequence of the model medicinal mushroom Ganoderma lucidum.Nat. Commun. 3:913. doi: 10.1038/ncomms1923

Hiramatsu, A., Kobayashi, N. and Osawa, N., 1987. Properties of two inhibitors of plant virus infection from fruiting bodies of Lentinus edodes and from leaves of Yucca recurvifolia Salisb. *Agricultural and biological chemistry*, *51*(3):897-904.

Jagadish, L.K., Krishnan, V.V., Shenbhagaraman, R. and Kaviyarasan, V., 2009. Comparitive study on the antioxidant, anticancer and antimicrobial property of Agaricus bisporus (JE Lange) Imbach before and after boiling. *African Journal of Biotechnology*, *8*(4).

Johansson, M., Sterner, O., Labischinski, H., Anke, T., 2001. Coprinol, a new antibiotic cuparane from *Coprinus* species. Z. Naturforsch. 56, 31–34.

Jonathan, S., and Fasidi, I. 2003. Antimicrobial activities of two Nigerian edible macrofungi- Lycoperdon pusilum and Lycoperdon gigantium. *African Journal of Biomedical research,6 (2)*: 25- 27.

Jose, N. and Janardhanan, K.K., 2000. Antioxidant and antitumour activity of Pleurotus florida. *Current Science*, *79*(7):941-943.

Jose, N., Ajith, T.A. and Janardhanan, K.K., 2002. Antioxidant, anti-inflammatory, and antitumor activities of culinary-medicinal mushroom Pleurotus pufmonanus (Fr.) Quel.(Agaricomycetideae). *International Journal of Medicinal Mushrooms*, *4*(4).

Klaus, A. and Niksic, M., 2007. Influence of the extracts isolated from Ganoderma lucidum mushroom on some microorganisms. *Zbornik Matice srpske za prirodne nauke*, *113*(219).26.

Koch, A.L., 2003. Bacterial wall as target for attack: past, present, and future research. *Clinical microbiology reviews*.*16*(4):673-687.

Kovalenko, O.G., Polishchuk, O.N., Wasser, S.P., 2009. Virus resistance induced by glucuronoxylomannan iso­lated from submerged cultivated yeast-like cell biomass of medicinal yellow brain mushroom *Tremella mesen­terica* Ritz.:Fr. (Heterobasidiomycetes) in hypersensitive host plants. *Int. J. Med. Mushrooms* 11 (2):199–205.

Kwak, A.M., Min, K.J., Lee, S.Y. 2015. Water extract from spent mushroom substrate of Hericium arinaceus suppress bacterial wilt disease of tomato. *Mycobiology, 43 (3)*: 311 - 318.

Li, W.-J., Nie, S.-P., Liu, X.-Z., Zhang, H., Yang, Y., Yu, Q., et al., 2012. Antimicrobial properties, antioxidant activity and cytotoxicity of ethanol-soluble acidic components from *Ganoderma atrum*. *Food Chem. Toxicol.* 50: 689–694

Lindequist, U., Nidermeuer, T.H., and Julich, W. D. 2005. The pharmological potential of mushroom. *Evidence based complmentary and alternative medicine, 2(3)*: 285 -299.

M. L., et al. (2007). Antiviral activity of aqueous and ethanol extracts and of an isolated polysaccharide from Agaricus brasiliensis against poliovirus type 1. Lett. A:l. *Microbiol. 45 :*24–28

Mizuno, T., 1995. Bioactive biomolecules of mushrooms: food function and medicinal effect of mushroom fungi. *Food Reviews International*, *11*(1):5-21.

Nozawa, C., et al. (2012). Polysaccharides and extracts from Lentinula edodes: structural features and antiviral activity. Virol. J. 15, 37.

Öztürk, M., Duru, M.E., Kivrak, Ş., Mercan-Doğan, N., Türkoglu, A. and Özler, M.A., 2011. In vitro antioxidant, anticholinesterase and antimicrobial activity studies on three Agaricus species with fatty acid compositions and iron contents: A comparative study on the three most edible mushrooms. *Food and Chemical Toxicology*, *49*(6), :.1353-1360.

Palacios, I., Lozano, M., Moro, C., D’arrigo, M., Rostagno, M. A., Martínez, J. A., ... & Villares, A. (2011). Antioxidant properties of phenolic compounds occurring in edible mushrooms. *Food chemistry*, *128*(3), 674-678.

Peralta, R.M., da Silva, B.P., Côrrea, R.C.G., Kato, C.G., Seixas, F.A.V. and Bracht, A., 2017. Enzymes from Basidiomycetes—Peculiar and Efficient Tools for Biotechnology. In *Biotechnology of microbial enzymes*. 119-149).

Quereshi, S., Pandey, A.K. and Sandhu, S.S., 2010. Evaluation of antibacterial activity of different Ganoderma lucidum extracts. *J Sci Res*, *3* :9-13.

Saddiqe, Z., Naeem, I., Maimoona, A., 2010. A review of the antibacterial activity of *Hypericum perforatum* L. *J. Ethnopharmacol. 131* :511–512.

Silva, R.F., Pascholati, S.F. and Bedendo, I.P., 2013. Induced resistance in tomato plants to Clavibacter michiganensis subsp. Michiganensis by Lentinula edodes and Agaricus subrufescens (syn. Agaricus brasiliensis). *Journal of plant pathology*:285-297.

Sliva, D., 2006. Ganoderma lucidum in cancer research. Leuk. Res. 30, 767–768.

Sun, H., Zhao, C.G., Tong, X., Qi, Y.P., 2003. A lectin with mycelia differentiation and antiphytovirus activities from the edible mushroom *Agrocybe aegerita*. J. Biochem. *Mol. Biol. 36 (2),* 214–222.

Tochikura, T.S., Nakashima, H., Ohashi, Y. and Yamamoto, N., 1988. Inhibition (in vitro) of replication and of the cytopathic effect of human immunodeficiency virus by an extract of the culture medium of Lentinus edodes mycelia. *Medical microbiology and immunology*, *177*(5), :.235-244

Wang, Y., Bao, L., Li, L., Li, S., Gao, H., Yao, X.-S., et al., 2012. Bioactive sesquiterpenoids from the solid culture of the edible mushroom *Flammulina velutipes* growing on cooked rice. Food Chem. 132, 1346–1353.

Ying, C.C., 1987. *Icons of medicinal fungi from China*. Science press.

Yu, J.-Q., Lei, J.-Ch., Zhang, X.-Q., Yu, H.-D., Tian, D.-Z., Liao, Z.-X., et al., 2011. Anticancer, antioxidant and antimicrobial activities of the essential oil of *Lycopus lucidus* Turcz. var*. hirtus* Regel. *Food Chem. 126*, 1593–1598

Zhang, W., Tao, J., Yang, X., Zhang, J., Lu, H., Wu, K., et al. (2014). Antiviral property and mode of action of a sulphated polysaccharide from Sargassum
patens against herpes simplex virus type 2. *Int. J. Antimicrob. Agents 24*,
 81–85.

Zjawiony, J.K., 2009. Antimicrobial and antiviral metabolites from polypore fungi. In *Novel Therapeutic Agents from Plants* :36-59. Science Publishers Enfield, New Hampshire.