

Chapter 2

Bioactives from Mushroom and Their Application

Carmen Sánchez

1 Introduction

This chapter describes the variety and biomedical potential of mushrooms as well as their bioactive compounds. It starts with a description of the structure, growth, and composition of mushroom fungi. A description of polyssacharides (e.g., β -glucan) and polysaccharide–protein complexes was found in different mushrooms, and their potential medical uses are mentioned. In addition, the immunomodulatory bioactivity of β -glucans is illustrated in this section. Terpene compounds as the largest group of anti-inflammatory compounds in mushrooms are addressed. The importance of phenolic compounds acting as free radical inhibitors, peroxide decomposers, metal inactivators, or oxygen scavengers in biological systems is described. Bioactive proteins and peptides, including lectins, which have no enzymatic activity, as well as those bioactive proteins possessing enzymatic activity such as fungal immunomodulatory proteins, ribosome-inactivating proteins, and laccases, are addressed. Finally, other compounds are able to reduce oxidative stress in the endoplasmic reticulum, demonstrating its potential effect in neurodegenerative diseases, and others showing antidepressant properties are also mentioned.

2 Mushroom: Structure, Growth, and Composition

Mushrooms are a very large and diversified group of macrofungi belonging to basidiomycetes and ascomycetes, which have two phases of growth: the reproductive phase (fruit bodies) and the vegetative phase (mycelia). These organisms are

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epigeous (grow above the earth) with the umbrella-shaped fruiting body, where spores are produced (in lamellae, structures on the underside of the pileus). The fungal spores for these two groups are located in a special structure called basidium (for basidiomycetes) or ascus (for ascomycetes). In the fungal growth, after spore germination (or inoculation of in vitro-grown mycelia), the substrate is invaded by microscopic filaments called hyphae. The cells in a hypha are separated by a cross-wall called septum. Hyphae continually grow and branch to form a network of hyphae or mycelia (mycelial growth). Mycelial growth is generally coupled with increased enzyme production and respiration. Hyphae absorb digestive products, penetrating the substrate to some extent. The fungal cell wall can be formed by mannoproteins, β -D-glucans, and chitin (Fig. 1). From the ecological point of view, mushroom fungi can be saprotrophs, parasites, and mycorrhiza. There are only few parasitic mushrooms. Most of the cultivated mushrooms are saprotrophs. Mycorrhizal mushrooms have a symbiotic relationship with some vegetation, mainly trees, having a relationship of mutual benefit. Saprotrophs are able to obtain nutrients from dead organic material, and parasites obtain their food from living animals and plants, causing harm to the host (Cheung 2008). Mushrooms have been eaten and appreciated for their exquisite flavor, economic and ecological values, and medicinal properties for many years. In general, mushrooms contain 90% water and 10% dry matter (Sánchez 2010). They have a chemical composition, which is attractive from the nutritional point of view (Dundar et al. 2008). Their nutritional value can be compared to those of eggs, milk, and meat (Oei 2003). Mushrooms contain vitamins (thiamine, riboflavin, ascorbic acid, ergosterol, and niacin) as well as an abundance of essential amino acids. They also have proteins, fats, ash, glycosides, volatile oils, tocopherols, phenolic compounds, flavonoids, carotenoids, folates, organic acids, etc. (Sánchez 2004; Patel and Goyal 2012). The total energetic value of mushroom caps is between 250 and 350 cal/kg of fresh mushrooms (Sánchez 2010). Mushrooms can be considered as functional food which provides health benefits in addition to nutritional value (Rathee et al. 2012). They have been collected in several countries for hundreds of years, and technological improvements have made possible their cultivation worldwide.

3 Bioactive Compounds in Mushroom

There has been an increasing interest in mushrooms as a source of biologically active compounds which provide to humans medicinal or health benefits such as the prevention and treatment of diseases (Rathee et al. 2012). Bioactive compounds can be found in mushroom as cell wall components such as polysaccharides (e.g., β -glucans) and proteins or as secondary metabolites such as phenolic compounds, terpenes, and steroids. The concentration and efficacy of the bioactive compounds are varied and depend on the type of mushroom, substrate, fruiting conditions (if cultivated), stage of development, age of the fresh mushroom, storage conditions, and cooking procedures (Guillamón et al. 2010). Many studies have reported that

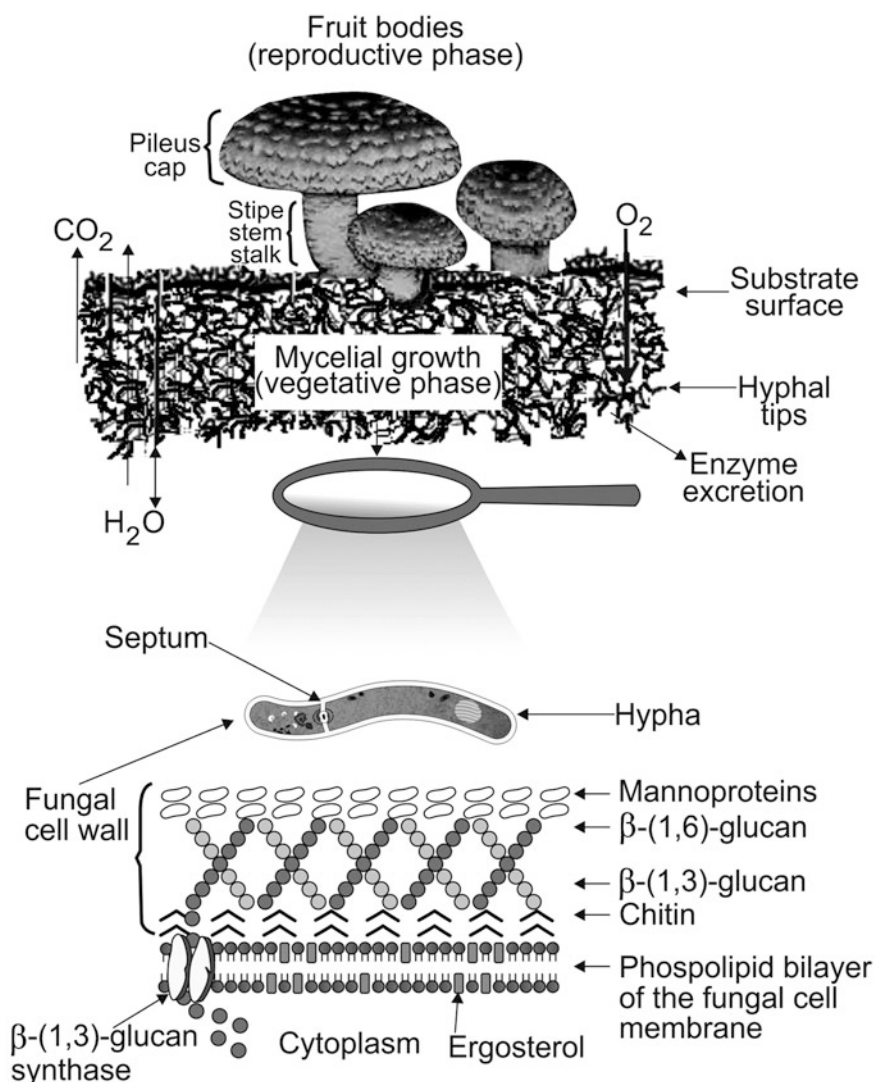


Fig. 1 Schematic representation of mushroom phases of growth and fungal cell wall composition

the medicinal properties of mushrooms include anti-inflammatory, antioxidant, immunomodulatory, anticarcinogenic, antiviral, antibacterial, antifungal, hepatoprotective, antineurodegenerative, antidiabetic, antiangiogenic, and hypoglycemic, among others (Badalyan 2012; Elsayed et al. 2014; Xu and Beelman 2015). Mushrooms' bioactive compounds on the basis of their chemical structure can be polysaccharides, phenolic compounds, terpenes and terpenoids, phenols, peptides, proteins, etc. (Table 1).

Table 1 Biologically active compounds from mushrooms and their medical applications

Mushroom Scientific name	Common names	Phyllum or group/Edibility	Bioactive compound	Bioactivity	Reference
<i>Agaricus bisporus</i>	Champignon, Button mushroom, White mushroom,	B/E	Pyrogallol hydroxybenzoic acid derivatives Flavonoids	Anti-inflammatory	Moro et al., 2012; Ndonguts et al., 2015
<i>Agaricus macrosporus</i>	Macro mushroom	B/E	Agaricoglycerides	Anti-inflammatory	Han and Cui, 2012
<i>Agaricus subinfescens</i> (= <i>Agaricus blazei</i> , <i>Agaricus</i> <i>brasiliensis</i> , <i>Agaricus rufotegulis</i>)	Almond mushroom, God's mushroom, Mushroom of life, Royal sun <i>Agaricus</i>	B/E	Glycoprotein, β -(1, 3)-glucan, with β -(1,6)-glucan branch Protein fractions and polysaccharides fractions	Immunomodulatory Immunomodulatory	Firenzuoli et al., 2007; Lima, 2008 Jeurink et al., 2008
<i>Agrocybe cylindracea</i> (= <i>Pholiota aegerita</i>)	Poplar mushroom	B/E	β -Glucans Agrocybin (peptide)	Anti-oxidant Hypoglycemic Anti-fungal	Rathee et al., 2012; Zhang et al., 2003 Gupta et al., 2014 Ngai et al., 2005
<i>Albatrellus ovinus</i> (= <i>Polyporus ovinus</i>)	Forest lamb mushroom, sheep polypore	B/E	Grifolin and grifolin derivatives	Anti-inflammatory Anti-oxidant	Nukata et al., 2002
<i>Albatrellus caeruleoporus</i>	Blue albatrellus	B/E	Phenolic compound Grifolinones A, B	Anti-inflammatory	Nukata et al., 2002 Quang et al., 2006
<i>Antrodia camphorata</i> (= <i>Taiwanofungus camphoratus</i>)	Stout camphor fungus	B/N/E	Glycoprotein ACA Diterpenes	Immunomodulatory Neuroprotective	Sheu et al., 2009 Chen et al., 2006

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Table 1 (continued)

Mushroom Scientific name	Common names	Phyllum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Auricularia auricula</i>	Jew's ear, wood ear, jelly ear	B/E	Glucan	Hyperglycemia Immunomodulatory Anti-tumor Anti-inflammatory	Zhang et al., 2007
<i>Boletus edulis</i>	Cep. penny bun, king bolete	B/E	Polysaccharides	Anti-inflammatory	Moro et al., 2012
<i>Boletus spp</i>	Gelam mushroom	B/E	2,4,6-trimethylacetophenone imine, glutamyl tryptophan, azatadine, lithocholic acid glycine conjugate	Anti-oxidant	Yuswan et al., 2015
<i>Cantharellus cibarius</i>	Chanterelle, golden chanterelle, girolle	B/E	Pyrogallol	Anti-inflammatory	Moro et al., 2012; Dugler et al., 2004
			Flavonoids	Anti-microbial	Palacios et al., 2011
			Polysaccharides		
<i>Calvatia gigantea</i>	Giant puffball	B/E	Caffeic acid, catechin	Anti-oxidant	
			Calvacin	Anti-tumor	Rahee et al., 2012
<i>Caripia montagnei</i>	Pod parachute	B/E	Polysaccharides (glucans)	Anti-inflammatory	Queiroz et al., 2010
<i>Clitocybe maxima</i>		B/NE	Laccase	Anti-tumor	Zhang et al., 2010b

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Coprinus comatus</i>	Shaggy ink cap, lawyer's wig, shaggy mane	B/E	β - 1,3-glucan	Immunomodulatory	Chan et al., 2009
			Protein fractions and polysaccharides fractions	Immunomodulatory	Jeurink et al., 2008
<i>Cordyceps militaris</i>	Beldar-mazo, deer fungus, caterpillar fungus	A/E	Cordycepin	Anti-inflammatory, Anti- angiogenic	Won et al., 2005; Kumar et al., 2010
			Cordymin	Anti-inflammatory	Das et al., 2010
					Wong et al., 2011
<i>Cordyceps sinensis</i>	Summer grass, winter worm	A/E	Cordycepin,	Anti-oxidant	Holliday et al., 2004
			Ciclosporin	Immunosuppressive	Holliday, 2005
			Cordymin (peptide)	Anti-inflammatory	Wang et al., 2012; Qian et al., 2011
<i>Cortinarius infractus</i>	Sooty-olive Cortinarius, the bitter webcap	B/NE	6-hydroxyinfractine, infractopticine	Anti-neurodegenerative	Brondz et al. 2007; Geissler et al., 2010
<i>Craterellus cornucopioides</i>	Black chanterelle, horn of plenty, black trumpet, trumpet of the dead.	B/E	Myricetin	Anti-oxidant	Palacios et al., 2011

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/Edibility	Bioactive compound	Bioactivity	Reference
<i>Craterellus tubaeformis</i>	Yellow foot, winter mushroom, funnel chanterelle	B/E	Polysaccharides	Anti-inflammatory	Tsvetkova et al., 2006
<i>Cyathus africanus</i>	Bird's nest fungi	B/NE	Diterpenoid (neosarcodonin, cyathatriol, and 11-O-acetylcycathatriol)	Anti-inflammatory	Han et al., 2013
<i>Daldinia concentrica</i>	King Alfred's Cake, cramp balls, coal fungus	A/NE	1-(3,4,5-trimethoxyphenyl) ethanol, caruillignan C	Neuroprotective	Lee et al., 2002b
<i>Dictyophora indusiata</i> (= <i>Phallus indusiatus</i>)	Veiled lady mushroom, bamboo mushroom	B/E	Dictyophorine A and B	Anti-neurodegenerative	Kawagishi et al., 1997
<i>Elaphomyces granulatus</i>	False Truffle	A/NE	Dictyoquinazol A, B, and C	Neuroprotective	Lee et al., 2002a
			Syringaldehyde, Syringic acid	Anti-inflammatory	Wang and Marcone., 2011
					Stanikunaitė et al., 2009
<i>Flammulina velutipes</i>	Golden needle mushroom, Enoki	B/E	Peptidoglycan	Anti-inflammatory, antiviral	Yin et al., 2010
			Polysaccharides	Anti-inflammatory	Wu et al., 2010
			Flammulin (protein)	Anti-tumor	Chen et al., 2003; Chang et al., 2010
<i>Fomitopsis pinicola</i>	Red-belt conk	B/NE	Polysaccharides	Anti-inflammatory	Cheng et al., 2008

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Ganoderma lucidum</i>	Reishi, lingzhi, mannentake	B/NE	Ganoderic acids, ganoderiol, ganodermanontriol,	Anti-tumor, anti-metastasis anti-HIV anti-viral	Xu et al., 2010, Walton, 2014; Xu and Zhong, 2012
			Ganoderan A and B	Hypoglycemic	El-Mekkawy et al., 1998
			Ganopoly	Hepatoprotective	Rai et al., 2005
			Triterpenes	Anti-inflammatory	Rathe et al., 2012
			Lucidenic acids and ganoderic acids	Anti-inflammatory	Gao et al., 2002;
			Lanostane-type triterpenic acids	Anti-inflammatory	Dudhgaonkar et al., 2009,
			Ling zhi-8 (protein)	Immunomodulatory	Akihisa et al., 2007;
			Ganodermin (protein)	Antifungal	Iwatsuki et al. (2003)
			Se-containing protein	Anti-tumor	Akihisa et al. (2005)
					Kino et al., 1989 Wang and Ng (2006b)
<i>Ganoderma microsporum</i>	LingZhi (Chinese name)	B/NE	Protein GMI	Immunomodulatory	Du et al., 2007 Lin et al., 2010

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Table 1 (continued)

Mushroom Scientific name	Common names	Phyllum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Ganoderma pfeifferi</i>	Paksulattakääpä (Finnish common name)	B/NE	Sesquiterpenoid hydroquinones (lucialdehyde D, ganoderone A, ganoderone C)	Anti-bacterial, anti-fungal, anti-viral	Niedermeyer et al., 2005
<i>Gaeastrum saccatum</i>	Rounded earthstar	B/NE	Polysaccharides (β -glucans)	Anti-inflammatory	Guerra-Dore et al., 2007
<i>Ganoderma tsugae</i> (= <i>Polyporus tsugae</i>)	Hemlock varnish shelf		Fip-gts (protein)	Immunomodulatory	Lin et al., 1997
<i>Grifola Frondosa</i>	Hen-of-the-woods, ram's head, sheep's head, maitake	B/E	Grifolan ¹ (1-6-monoglucosyl-branched β -1,3-glucan) Proteoglycan, Heteroglycan, Galactomannan, Glucoxylan Mannogalactofucan Fucomannogalactan Agaricoglycerides	Immunomodulatory anti-tumor, Anti-viral, hepatoprotective Anti-inflammatory	Yang, 2007; Kidd et al., 2000
			Low-molecular weight protein fraction	Anti-tumor	Han and Cui, 2012
					Kodama et al., 2002

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Hericium erinaceus</i>	Lion's mane mushroom, bearded tooth, Satyr's Beard, pom-pom mushroom, bearded tooth fungus	B/E	Phenol-analogous compounds (hericenons C, D, E, F, G, H)	Anti-oxidant	Wang et al., 1996
			Hericenons Erinacines, hericerins, resorcinols, steroids, mono-terpenes, diterpenes	Anti-biotic, anti-carcinogenic, anti-diabetic, anti-fatigue, anti-hypertensive, anti-hyperlipodemic,	Mizuno, 1999
			Heteroglycan peptide, β -1,3 branched- β -1,2-mannan	Hyperglycemia, Immunomodulatory anti-tumor	Lee et al., 2009; Friedman, 2015
				Anti-senescence, cardioprotective, hepatoprotective, nephroprotective, neuroprotective, etc.	
			Lectin (glycoprotein)	Anti-tumor, Anti-virus	
			Hericenones (A-H), Erinacines (A-K, P-Q),	Anti- neurodegenerative	Li et al., 2010b
			Dilinoleoylphosphatidylethanolamine	Anti-neurodegenerative	Xu and Beelman, 2015; Phan et al., 2014 Nagai et al., 2006

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Hypsizygus marmoreus</i> (= <i>Hypsizygus tessellatus</i>)	Brown Beech, buna - shimeji	B/E	Ergosterol, manitol,	Anti-oxidant, anti-inflammatory,	Yoshino et al., 2008
			Trehalose, methionine	Anti-allergic	Wong et al., 2008
			Marmorin	anti-tumor activity	Chowdhury et al., 2015
<i>Inonotus obliquus</i>	Chaga, clinker polypore, cinder conk, black mass	B/E	Phenolic compounds flavonoids	Anti-bacterial, antifungal, anti-oxidant	
			β -D-glucans	Anti-oxidant, stomach diseases, cancer	Rathee et al., 2012
			Mannogalactoglucan	Anti-tumor,	Wasser, 2010
			Sterols	Anti-inflammatory	Van et al., 2009; Park et al., 2005
			Triterpenes	Anti-inflammatory, anti-cancer	Ma et al., 2013
<i>Lactarius deliciosus</i> (= <i>L. flavidulus</i>)	Saffron milk cap, red pine mushroom	B/E	Pyrogallol, Flavonoids	Anti-inflammatory	Moro et al., 2012
			Polysaccharides	Anti-inflammatory	Fijimoto et al., 1993
<i>Lactarius rufus</i>	Rufous milk cap, red hot milk cap	B/E	Polysaccharides: (1,3), (1,6) β -D-glucans	Anti-inflammatory	Ruthes et al., 2013

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Table 1 (continued)

Mushroom Scientific name	Common names	Phyllum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Lentinula edodes</i>	Shiitake,	B/E	Lentinan, glucan, mannoglucan,	Immunomodulatory antitumor,	Sasaki and Takasuka, 1976; Israelides et al., 2008
			Fucomannogalactan	Anti-inflammatory	Attarat and Phermthai, 2015
			Lentin (protein)	Anti-fungal	Ngai and Ng, 2008
			Catechin (Phenolic compound)	Anti-oxidant	Chowdhury et al., 2015
<i>Lentinula polychrous</i>	NA	B/NE	Phenolic compounds flavonoids	Anti-bacterial, antifungal, anti-oxidant	
<i>Lentinula squarrosulus</i>	NA	B/NE	Catechin	Anti-oxidant	Attarat and Phermthai, 2015
<i>Lenzites betulina</i>	Gilled polypore, birch maze gill, multicolor gill, polypore	B/NE	Catechin	Anti-oxidant	Attarat and Phermthai, 2015
			Betulinan A	Anti-oxidant	Rathee et al., 2012
<i>Lignosus rhinocerus</i>	Tiger milk mushroom	B/NE	Polysaccharides-protein	Anti-cancer	Gupta et al., 2015
<i>Lyophyllum decastes</i>	Fried chicken mushroom	B/E	Polysaccharides: (1, 3) and (1,6) β -D-glucans	Anti-inflammatory	Ukawa et al., 2000

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Table 1 (continued)

Mushroom Scientific name	Common names	Phyllum or group/Edibility	Bioactive compound	Bioactivity	Reference
<i>Mycoleptodonoides aitchisonii</i>	Bunaharitake	B/E	3-(hydroxymethyl)-4-methylfuran-2(5H)-one, (3R,4S,1'R)-3-(1'-hydroxy-ethyl)-4methylidihydrofuran-2(3H)-one, 5-hydroxy-4-(1-hydroxyethyl)-3-methylfuran-2(5H)-one, 5-phenylpentane-1,3,4-triol	Anti-neurodegenerative	Choi et al. 2009; Choi et al., 2014
<i>Morchella esculenta</i>	Common morel, Morel, Yellow morel, True morel, Morel mushroom, Sponge morel	A/E	Heteroglycan Galactomannan, β -1,3-D-glucan	Hyperglycemia, Anti-tumor	Cheung, 2008
<i>Phellinus linteus</i>	Black hoof mushroom	B/NE	Glucans Acidic polysaccharides	Anti-tumor Immunomodulatory	Kim and Iwahashi, 2015 Hsieh et al., 2013; Wu et al., 2013
<i>Pholiota adiposa</i>	Fatty pholiota, pineapple pholiota, sticky pholiota	B/E	Hispidin (polyphenol) Lectin (glycoprotein)	Anti-oxidant Anti-tumor Anti-viral	Park et al., 2004 Zhang et al., 2009
<i>Pholiota nameko</i>	Nameko, butters cotch mushroom	B/E	Polysaccharides	Anti-inflammatory	Li et al., 2008

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Pleurotus citrinopileatus</i>	Golden oyster mushroom	B/E	Glycoprotein (PCP-3A)	Anti-tumor anti-cancer	Chen et al., 2009
<i>Pleurotus eryngii</i>	King trumpet mushroom, French horn mushroom, king oyster mushroom	B/E	laccase	Anti-viral	Wang and Ng, 2006a.
<i>Pleurotus florida</i>	White oyster	B/E	β -glucans	Anti-oxidant	Ganeshpurkar et al., 2015
<i>Pleurotus ostreatus</i>	Oyster mushroom	B/E	Pleuran (β -1, 3-glucan with galactose and mannose), proteoglycan	Immunomodulatory Anti-tumor, hyperglycemia, anti-oxidant	El Enshasy et al., 2013b Tong et al., 2009
			Laccase	Anti-viral	El Fakharany et al., 2010
			Pleurostin (peptide)	Anti-fungal	Chu et al., 2005
<i>Pleurotus pulmonarius</i>	Indian Oyster, Italian oyster, phoenix mushroom, lung oyster	B/E	Polysaccharides β (1,3)-glucopyranosyl Polysaccharides (1,3), (1,6)-linked β -glucan	Anti-inflammatory	Lavi et al., 2012 Smirdele et al., 2008

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Table 1 (continued)

Mushroom Scientific name	Common names	Phyllum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Psilocybe species</i> (eg. <i>P. cubensis</i> , <i>P. samuensis</i> , <i>P. Mexicana</i>)	Magic mushroom, shrooms	B/NE (hallucinogen)	Psilocybin (psilocin: 4-hydroxy-dimethyltryptamine)	Anti-depressant (Psychotherapy)	Mason-Dambrot, 2012; Kraehenmann, 2015; Grob et al., 2011; Carhart-Harris et al., 2012; Petri et al., 2014
<i>Russula lepida</i> (= <i>Russula rosea</i>)	Rosy russula	B/NE	Lectin (glycoprotein)	Anti-tumor	Zhang et al., 2010a
<i>Schizophyllum commune</i>	Split Gill	B/NE	Schizophyllan, 1,6- monoglucosyl branched β -1, 3- D-glucan	Immunomodulatory Anti-tumor	Bae et al., 2004; Hobbs, 2005
<i>Sparassis crispa</i>	Rooting cauliflower mushroom	B/E	β -Glucan	Immunomodulatory	Ohno et al., 2002; Takashi, 2013
<i>Termitomyces albidinostus</i> (= <i>Macrolepiota albidinosa</i>)	Termite mushroom	B/E	Termitomycesphins (cerebrosides)	Anti- neurodegenerative	Qi et al., 2000; Qu et al., 2012
<i>Trametes versicolor</i> (= <i>Coriolus versicolor</i> <i>Polyporus versicolor</i>)	Wild turkey	B/E, unpalatable)	Termitomycamides (fatty acid amides) Krestin (PKS), (PSP) Coriolan (β -glucanprotein complex)	Anti- neurodegenerative Anti-metastatic Hypoglycemic	Choi et al., 2010 Wasser, 2002 Rathee at al., 2012

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Tremella aurantia alba</i>	Golden ear	B/E	Heteroglycan	Immunomodulatory	Du et al., 2010
<i>Tremella mesenterica</i>	Yellow brain, golden jelly fungus, yellow trembler, witches butter	B/E	Glucurono-xylomannan polysaccharide	Hypoglycemic Immunomodulatory	Gupta et al., 2014
<i>Tricholoma giganteum</i>	Giant mushroom		Trichogin (protein)	Antifungal	Guo et al., 2005
<i>Tricholoma mongolicum</i>	NA	B/E	Laccase	Anti-viral, anti-tumor	Wang et al., 1996; Li et al., 2010a
<i>Volvariella volvacea</i>	Paddy straw mushroom, straw mushroom		Fip-vvo	Immunomodulatory	Hsu et al., 1997
<i>Wolfiporia cocos</i> (= <i>Poria cocos</i>)	Hoelen, poria, tuckahoe, China root,	B/NE	Dehydrotremetenolic acid	Hypoglycemic	Rathee et al., 2012
			Lanostane	Anti- inflammatory agents	Zheng and Yang, 2008a; 2008b

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Table 1 (continued)

Mushroom Scientific name	Common names	Phylum or group/ Edibility	Bioactive compound	Bioactivity	Reference
<i>Xylaria hypoxylon</i>	Candlestick fungus, candle snuff fungus, carbon antlers, stag's horn fungus	A/NE	Lectin (glycoprotein)	Anti-mitogenic anti-tumor	Liu et al., 2006

B: Basidiomycota
A: Ascomycota
E: Edible
NE: Non-edible
NA: not available

3.1 Polysaccharides

Polysaccharides are the major class of bioactive compounds found in mushroom and have been reported in most of the edible mushrooms. The general therapeutic effects of polysaccharides are antioxidant, antidiabetic, antimicrobial, anti-inflammatory, anticancer, and immunomodulators (Elsayed et al. 2014; Chan et al. 2009).

3.1.1 Glucans

Glucan polysaccharides differ in their primary structure (type of basic sugar, e.g., xylose, mannose, galactose, etc.), type of linkage (α or β), degree of branching, molecular weight, solubility, etc. Fungal glucans can be water soluble, soluble in alkali or insoluble. Some glucans are intracellular (serve as reserve material), others are secreted in the medium, and few are present in the cell wall (Ruiz-Herrera 2012). The insoluble fractions are usually structural components of the cell wall and cross-linked to other polysaccharides like chitin or to proteins (e.g., mannoproteins and glycoprotein). Soluble glucans correspond to 20–50% of the total glucans, and insoluble glucans correspond between 50 and 80% (He et al. 2012). The diversity of glucans results from at least eight different ways in which two glucose units can link. Formations of α - or β -bond are a result of the condensation reactions. The diversity of glucans is further increased due to the different length and branches of

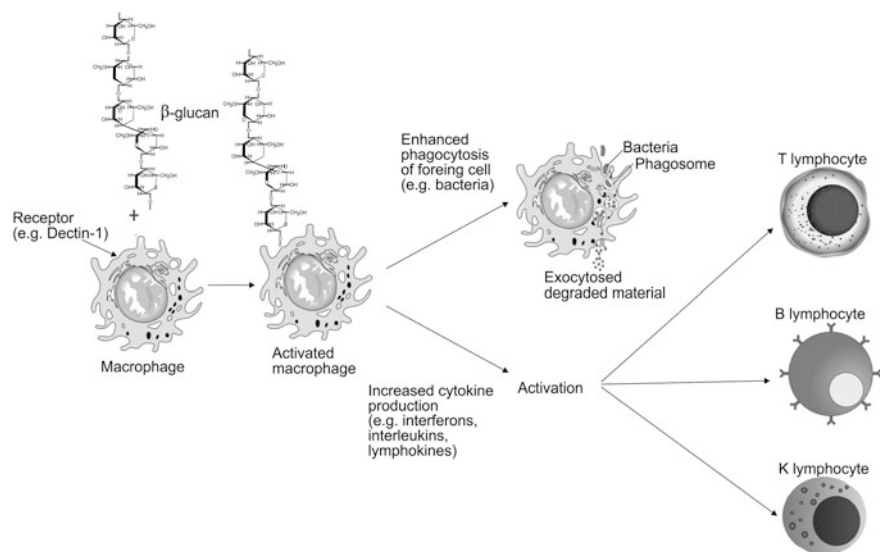


Fig. 2 Schematic illustration of the mechanism of immune activation by β -glucan from mushrooms

chains and substitutions on the sugar rings (Ren et al. 2012). β - and α -glucans can be present in fungal cell wall. Fruit body extracts of *Pleurotus pulmonarius* showed mixed α -linkages and β -anomeric carbon linkages, whereas polysaccharide from mycelial extracts had mainly α -glucan linkages (Lavi et al. 2010). α (1, 3)-glucan is present at levels of 9–46% of the cell wall in several basidiomycetes. It can be present in the cell wall of certain mushrooms such as *Agaricus bisporus* fruit bodies (Smiderle et al. 2010). β -glucan is one of the key components of several basidiomycete and ascomycete cell wall. It is a long-chain polysaccharide with β -D glucose as basic subunit linked to one another by 1-3 glycosidic chain with 1-6 glycosidic branches. β -glucans have been reported to have antimicrobial immune response, acting on several immune receptors such as dectin-1 (major β -glucan receptor), complement receptor (CR3), and TLR-2/6 (Toll-like receptor-2/6, receptor of the innate immune) (Chan et al. 2009). Therefore, β -glucans are able to enhance the immune system and prevent and treat several common diseases to promote health (Batbayar et al. 2012). In the innate immune system, β -glucan binds with macrophages that are responsible to detect intruders and coordinate the body defense system. Macrophages start out as monocytes (white blood cells), which leave the bloodstream and turn into macrophages. Macrophages are activated by β -glucan, enhancing their ability to identify and destroy intruders through phagocytosis. Macrophages also play an important role in activating the rest of the immune system (T lymphocyte, B lymphocyte, and NK cells) to destroy invaders. T lymphocytes (thymus-derived) have a receptor for antigen (T cell receptor) and are specialized cells trained to kill invaders. B lymphocytes (bone marrow-derived) make antibody, and their antigen receptor is the antibody on their surface. NK (natural killer) cells are T lymphocytes, which kill virus or bacterium-infected cells and tumor cells. In this way, the immune system protects the body from harmful invaders (Chan et al. 2009; Legentil et al. 2015) (Fig. 2). The bioactive glucans have been isolated from mushroom fruit bodies and from mycelia produced via submerged fermentation (Song et al. 2012; Queiroz et al. 2010; Guerra-Dore et al. 2007; Ruthes et al. 2013; Li et al. 2008). Several biologically active fungal β -glucans have been found in the fruiting bodies from mushrooms. Karácsonyi and Kuniak (1994) described the isolation of pleuran from *Pleurotus ostreatus* which is made of β (1,4)- or β (1,6)-branched for every fourth β (1,3)-glucan backbone (El Enshasy et al. 2013a). The bioactive glucan, lentinan from *Lentinula edodes*, is made of one β (1,6)-branched residue for every three β (1,3) glucose residues with molecular weight of 400–1000 kDa (Sasaki and Takasuka 1976). It showed immunomodulatory and antitumor activities (Firenzuoli et al. 2007). Schizophyllan is the active β -glucan from *Schizophyllum commune* which is formed by one β (1,6)-branched residue for every three β (1,3) glucose residues with molecular weight of 450 kDa (Bae et al. 2004). Maitake D-fraction was isolated from *Grifola frondosa*, which is made of mixture of β (1,6)-glucan main chain with β (1,4)-branched glucan and β (1,3)-glucan main chain with β (1,6)-branched glucan (Grifolan) (Kidd 2000). For example, *Agaricus subrufescens* extract is rich in β (1,3)-, β (1,4)-, and β (1,6)-glucans and induces the release of proinflammatory cytokines in human monocytes

and human vein endothelial cells in vitro (Bernardshaw et al. 2005). Glucans such as (1,3)-glucopyranosyl from *Pleurotus pulmonarius* have been reported to exhibit anti-inflammatory properties (Lavi et al. 2012). Rathee et al. (2012) reported that ganoderan A and B, glucans from *Ganoderma lucidum* fruiting bodies, showed hypoglycemic effects. On the other hand, ganopoly, the polysaccharide-containing preparation of *G. lucidum*, exhibited hepatoprotective effects in patients with chronic hepatitis B (Gao et al. 2002). It has been suggested that glucans from *G. lucidum* had immunomodulating properties, as well as enhancement of lymphocyte proliferation and antibody production. These polysaccharides also showed both antigenotoxic and antitumor-promoting activities (Bao et al. 2001; Wasser 2002). The antioxidative and free radical scavenging effects of polysaccharides of *G. lucidum* have also been reported (Rathee et al. 2012). A β -glucan (β -1,3-linked glucose residues, which occasionally branches at O-6) isolated from the fruiting bodies of *P. ostreatus* has also been proven to exert antitumor activity against HeLa tumor cell (Tong et al. 2009). Two mechanisms have been proposed to be responsible for the anticancer effect of β -glucan: (1) via direct cytotoxic effect and (2) indirectly through immunomodulatory action (Chan et al. 2009). *L. edodes* has shown anti-inflammatory activities. The active fraction was made of fucomannogalactan with a main chain of (1,6)-linked α -D-galactopyranosyl units, partially substituted at O-2 (Carbonero et al. 2008). Additionally, glucans such as (1,3)-D-glucopyranosyl from *P. pulmonarius* have been reported to exhibit anti-inflammatory properties (Lavi et al. 2012). Wu et al. (2010) reported that polysaccharides of *Flammulina velutipes* are composed of three monosaccharides (glucose, mannose, and xylose) in a molar ratio of 3.5:0.8:1.4 and have been found to have anti-inflammatory activities (Wu et al. 2010). Polysaccharides extracted from mushrooms such as *Cantharellus tubaeformis* (Tsvetkova et al. 2006), *Lactarius flavidulus* (Fujimoto et al. 1993), *Lactarius rufus* (Ruthes et al. 2013), *Lyophyllum decastes* (Ukawa et al. 2000), *Pholiota nameko* (Li et al. 2008), *Geastrum saccatum* (Guerra-Dore et al. 2007), *Fomitopsis pinicola* (Cheng et al. 2008), *Craterellus tubaeformis* (Tsvetkova et al. 2006), *Auricularia auricula* (Zhang et al. 2007), and *Boletus edulis* (Moro et al. 2012) have also been reported 'to exhibit anti-inflammatory properties.

3.1.2 Polysaccharide–Protein Complexes

Some polysaccharides have been identified as polysaccharide–protein complexes, which have been shown to possess immunomodulatory and antitumor activities. For example, polysaccharide-K (polysaccharide-Kureha; PSK) also known as krestin, protein bound with β (1,6) side chain, and β (1,3)-branched β (1,4) main chain glucan (94–100 kDa) were isolated from *Trametes versicolor*. Krestin showed antimetastatic activity (Fisher et al. 2002; Wasser 2002). Coriolan, a β -glucanprotein complex obtained from submerged grown *T. versicolor* biomass, exhibited hypoglycemic effects and ameliorated the symptoms of diabetes (Rathee et al. 2012). Chatterjee et al. (2011) isolated calvacin from *Calvatia gigantea*. It is a moderately

heat stable, nondiffusible, and basic mucoprotein, which showed antitumor activity. On the other hand, ethanolic extracts and a proteoglycan purified from *Phellinus linteus* showed anti-inflammatory properties (Kim et al. 2003, 2004).

3.2 Terpenes

Terpenes are the largest group of anti-inflammatory compounds in mushrooms. Several terpenes have been isolated from *G. lucidum*. These are nonpolar metabolites comprised of the following groups: (1) volatile mono and sesquiterpenes oils (C10 and C15), (2) less volatile diterpenes (C20), (3) involatile triterpenoids and sterols (C30), and (4) the carotenoid pigments (C40). Triterpene chemical structures are based on lanosterol. It is an important intermediate for their synthesis. Stereochemical rearrangement of this compound among triterpenoids results in their structural diversity (predominant pairs of C-3 stereoisomers) (Paliya et al. 2014). Akihisa et al. (2005) and Iwatsuki et al. (2003) isolated nine lucidenic acids and four ganoderic acids from fruit bodies of *G. lucidum*. On the other hand, several lanostane-type triterpenic acids were isolated by Akihisa et al. (2005) and terpenoids (triterpenes) were also isolated from Reishi mushroom (Dudhgaonkar et al. 2009). All those terpenes showed anti-inflammatory activity. Some triterpenes from *G. lucidum* (ganoderic acid C and derivatives) are able to inhibit the biosynthesis of cholesterol (Komoda et al. 1989). Other triterpenes (ganoderic acid F) of this mushroom contribute to atherosclerosis protection (Morigiwa et al. 1986). The antioxidative and free radical effects of triterpenoids from *G. lucidum* have also been shown (Rathee et al. 2012). El-Mekkawy et al. (1998) reported that different triterpenes from *G. lucidum* (i.e., ganoderiol, ganodermanontriol, and ganoderic acid) showed antiviral activity. Sterols and triterpenes (e.g., lucialdehyde D, ganoderone A, and ganoderone C) were isolated from the fruiting bodies of *Ganoderma pfeifferi*. Antifungal, antibacterial, and antiviral properties were found for some of such isolated compounds (Niedermeyer et al. 2005). Furthermore, different sterols with potent anti-inflammatory properties have been also isolated from *Inonotus obliquus* (Van et al. 2009; Park et al. 2005). Several triterpenes (trametenolic acid, ergosterol peroxide, 3 β -hydroxy-8,24-dien-21-al, ergosterol, and inotodiol) were isolated from the sclerotia of *I. obliquus*, which had anti-inflammatory and anticancer activities (Ma et al. 2013). Han et al. (2013) isolated five novel cyathane diterpenes (identified as cyathins DH) and three diterpenes (neosarcodonin, cyathatriol, and 11-O-acetylcylathatriol) from *Cyathus Africans*, which showed potent anti-inflammatory properties. Chen et al. (2006) reported that several triterpenes (e.g., 19-hydroxylabda-8(17)-en-16,15olide, and 14-deoxy-11,12-didehydroandrographolide) isolated from *Antrrodia camphorate* showed neuroprotective activity.

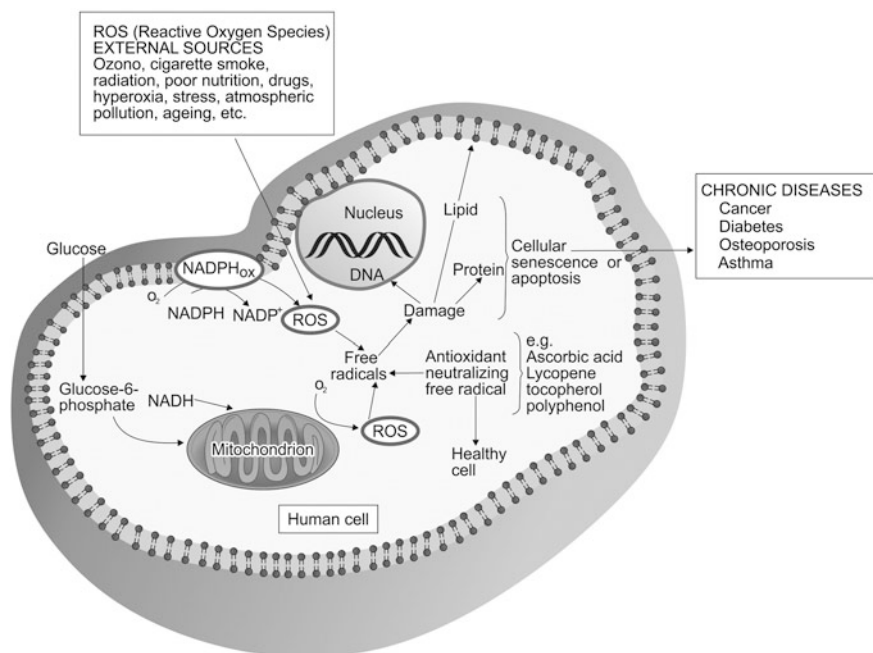


Fig. 3 Schematic representation of antioxidant activity, showing molecules neutralizing free radicals to prevent cellular and tissue damage

3.3 Phenolic Compounds

Phenolic compounds are aromatic hydroxylated compounds with one or more aromatic rings and one or more hydroxyl groups. They include phenolic acids, flavonoids, hydroxybenzoic acids, hydroxycinnamic acids, lignans, tannins, stilbenes, and oxidized polyphenols (Cote et al. 2010; D'Archivio et al. 2010). It has been reported that phenolic compounds exhibit antioxidant activity in biological systems, acting as free radical inhibitors, peroxide decomposers, metal inactivators, or oxygen scavengers (Dziezak 1986; Yagi 1970). Therefore, the key role played by antioxidants in the body is their ability to react with free radicals. A free radical is a chemical compound that contains one or more unpaired electrons. Reactive oxygen species (ROS) (i.e., superoxide, hydrogen peroxide, hydroxyl radical, hydroxyl ion, and nitric oxide) are reactive molecules and free radicals derived from molecular oxygen. These molecules can be produced either by external sources (e.g., cigarette smoke, ozone, and stress) or as by-products during the mitochondrial electron transport of aerobic respiration or by oxidoreductase enzymes and metal-catalyzed oxidation. Because they are reactive, radicals search out ways of pairing up their electron, so radicals often attack nearby chemical compounds. These chemical compounds may be involved in important enzyme reactions, may be components of

cell walls (i.e., lipid and protein), or may be part of a DNA molecule. If their chemical structure is changed, their function in the cell may be lost and the result can be cellular senescence or apoptosis (chronic diseases in the body). ROS have the potential to cause several deleterious events, and neutralizing of free radicals or peroxide radicals by an antioxidant agent may avoid such damage in the cell (Fig. 3). There are a number of nonenzymatic small molecules that play a role as antioxidants. Glutathione may be the most important intracellular defense against the deleterious effects of ROS. It is a tripeptide (glutamyl-cysteinyl-glycine), which provides an exposed sulfhydryl group as target for attack. Ascorbic acid (vitamin C) and α -tocopherol (vitamin E), lycopene, and polyphenol are examples of molecules capable of reducing ROS (Held 2015) (Fig. 3). Palacios et al. (2011) studied the antioxidant activity of phenolic compounds in *Agaricus bisporus*, *Boletus edulis*, *Cantharellus cibarius*, *Craterellus cornucopioides*, *Calocybe gambosa*, *Hygrophorus marzuolus*, and *Lactarius deliciosus*, and *P. ostreatus*. *C. cibarius*, and *C. cornucopioides* exhibited the greatest antioxidant effect with respect to the other species. *C. cornucopioides* showed the highest myricetin amount, and *C. cibarius* presented greater amounts of caffeic acid and catechin. The phenolic molecule pyrogallol has been extracted from *A. bisporus*, *C. cibarius*, and *L. deliciosus* (Dugler et al. 2004; Witkowska et al. 2011), which have been found to exhibit anti-inflammatory activity. Grifolin and grifolin derivatives are farnesyl phenolic compounds which have been isolated from the edible mushroom *Albatrellus ovinus*, which showed anti-inflammatory properties (Nukata et al. 2002). It has been reported that phenol analogous compounds (hericenones C, D, E, F, G, H) isolated from *H. erinaceus* had antioxidant activity (Mizuno 1999) and antineurodegenerative properties (Xu and Beelman 2015). Human trials have been carried out using *H. erinaceus*. In this study, 30 subjects were randomized into two 15-person groups, one of which was given *H. erinaceus* (250 mg tablets containing 96% of this mushroom dry powder) and the other given a placebo. The tablets were taken for three times a day for 16 weeks. Those subjects whose took *H. erinaceus* power showed significantly increased scores on the cognitive function scale compared with the placebo group (Mori et al. 2009). On the other hand, Attarat and Phermthai (2015) reported that catechin, a major group of phenolic compounds, was isolated from *Lentinula squarrosulus*, *Lentinula polychrous*, and *L. edodes*, which exhibited antioxidant activity. Chowdhury et al. (2015) isolated phenolic compounds and flavonoids from *P. ostreatus*, *L. edodes*, and *Hypsizygus tessellatus*, which showed antioxidant, antifungal, and antibacterial properties. On the other hand, it has been suggested that an increased free radical generation and the consequent elevated oxidative stress in neural system cause neurodegenerative diseases. Mushrooms can potentially reduce the risk of neurodegenerative diseases attributing to the high antioxidative capacity of bioactive compounds such as vitamin D and polyphenols (Xu and Beelman 2015). It has been reported that hericenones (A-H) and erinacines (A-K & P-Q), from fruiting bodies and mycelia of *H. erinaceus*, respectively, induced nerve growth factor synthesis (both in vitro and in vivo) (Kawagishi et al. 2008; Phan et al. 2014). Dai et al. (2010) reported that hispidin, a class of polyphenols, is an important medicinal metabolite from

Phellinus spp. Hispidin was isolated from the culture broth of *P. linteus*, and it has been shown to be an efficient ROS scavenger (Park et al. 2004).

3.4 Peptides and Proteins

Mushrooms produce many bioactive proteins and peptides, primarily including lectins, which have not enzymatic activity. Mushrooms also produce bioactive proteins, which possess enzymatic activity such as fungal immunomodulatory proteins (FIPs), ribosome-inactivating proteins (RIPs), and laccases. Chu et al. (2005) isolated an antifungal peptide (pleurostrin) (7 kDa) from *P. ostreatus*, which exhibited antifungal activity. Wang et al. (2007) isolated a peptide (SU2) (4.5 kDa) from *Russula paludosa*, which showed antiviral properties. Ngai et al. (2005) isolated an antifungal peptide (agrocybin) (9 kDa) from fresh fruiting bodies of the mushroom *Agrocybe cylindracea*. Cordymin, a low molecular weight peptide (10,906 Da), has been purified from *Cordyceps sinensis* (a highly prized edible fungus found in the mountains of Sichuan, Yunnan, and Tibet) (Wang et al. 2012; Qian et al. 2011) and from *Cordyceps militaris* (Wong et al. 2011). This peptide showed anti-inflammatory activity. Lectins are nonimmune proteins or glycoproteins that bind specifically to fungal cell wall carbohydrates and have ability to cell agglutination. Liu et al. (2006) isolated a xylose-specific lectin (28.8 kDa) from fresh fruiting bodies of *Xylaria hypoxylon*. It showed potent antimutagenic and antitumor activities. It has been reported that lectins were isolated from *Pholiota adiposa* and from *H. erinaceum* (16 and 51 kDa, respectively), which exhibited antiviral and antitumor activities (Zhang et al. 2009; Lin et al. 2010). Zhang et al. (2010a) isolated a lectin (32 kDa) from *Russula lepida*, which exhibited antitumor activity. Ribosome-inactivating proteins (RIPs) are enzymes that inactivate ribosomes by eliminating adenosine residues from rRNA. It has been reported that a ribosome-inactivating protein (9 kDa) (marmorin) was isolated from *Hypsizygus marmoratus* and showed antitumor activity (Wong et al. 2008). On the other hand, laccases are phenol oxidases widely diffused in basidiomycete and ascomycete fungi. These fungi use laccases to degrade lignocellulosic substrates. However, laccases with antiviral activity have been isolated from *Pleurotus eryngii* (Wang and Ng 2006a) and from *P. ostreatus* (El Fakharany et al. 2010). Zhang et al. (2010b) purified a laccase from *Clitocybe maxima*, which also showed antitumor activity. Some proteins targeting immune cells known as fungal immunomodulatory proteins (FIPs) are a new group bioactive proteins also isolated from mushroom. Kino et al. (1989) isolated ling zhi-8 (LZ-8), an immunomodulatory protein from *G. lucidum*. FIPs have been isolated from the mushrooms *F. velutipes* (Fip-fve) (Ko et al. 1995), *Ganoderma tsugae* (Fip-gts) (Lin et al. 1997), and *Volvariella volvacea* (Fip-vvo) (Hsu et al. 1997). It has been reported the potential application of Fip-fve for tumor immunotherapy (Ding et al. 2009; Chang and Sheu 2006; Chang et al. 2010). A novel immunomodulatory glycoprotein ACA (27 kDa) was purified from *Antrodia camphorata* (Sheu et al. 2009). Lin et al. (2010) isolated

an immunomodulatory protein GMI from *Ganoderma microsporum*, which showed antimetastasis activity. Du et al. (2007) purified a water-soluble Se-containing protein Se-GL-P (36 kDa) from the Se-enriched *G. lucidum*, which exhibited antitumor activity. The immunomodulatory activity of the isolated protein fractions and polysaccharide fractions from the mushrooms *A. blazei*, *C. comatus*, *F. velutipes*, *G. lucidum*, *G. frondosa*, *L. edodes*, *P. ostreatus*, and *V. volvacea* has been reported (Jeurink et al. 2008). Maiti et al. (2008) examined the antiproliferative and immunomodulatory activities of a protein fraction, named Cibacron blue affinity eluted protein (CBAEP), which was isolated from *Astraeus hygrometricus*, *Termitomyces clypeatus*, *Pleurotus florida*, *Calocybe indica*, and *V. volvacea*. A glycoprotein (PCP-3A) was purified from *Pleurotus citrinopileatus*, which showed antitumor activity (Chen et al. 2009). Kodama et al. (2002) isolated a low molecular weight protein fraction from *G. frondosa*, which showed antitumor activity. Ngai and Ng (2008) isolated a novel and potent antifungal protein lentin (27.5 kDa) from the fruiting bodies of *L. edodes*. Guo et al. (2005) also isolated an antifungal protein (trichogin) from *Tricholoma giganteum*. Wang and Ng (2006b) isolated an antifungal protein (15 kDa) (ganodermin) from *G. lucidum*. Zheng et al. (2010) isolated a novel antibacterial protein (44 kDa) from dried fruiting bodies of *Clitocybe sinopica*.

3.5 Other Compounds

Agaricoglycerides are fungal secondary metabolites that constitute esters of chlorinated 4-hydroxy benzoic acid and glycerol, which are produced in the culture of *G. frondosa* and *Agaricus macrosporus*. These compounds showed potent anti-inflammatory activity (Han and Cui 2012). Nagai et al. (2006) reported that dilinoleoylphosphatidylethanolamine isolated from fruiting bodies of *H. erinaceum* reduces oxidative stress in endoplasmic reticulum, demonstrating its potential effect in neurodegenerative diseases. It has been reported that termitomycesphins A, B, C, D, G, and H (cerebrosides) (Qi et al. 2000; Qu et al. 2012) and termitomycamide A, B, C, D, and E (fatty acid amides) were extracted and identified from dried fruiting bodies of *Termitomyces albuminosus* (Choi et al. 2010). These bioactive compounds also exhibited antineurodegenerative activity, since reduced endoplasmic reticulum stress-induced. Kawagishi et al. (1997) isolated dictyophorine A and B from *Dictyophora indusiata*, which can significantly improve the amount of nerve growth factor. Lee et al. (2002a) identified dictyoquinazol A, B, and C in *D. indusiata*, which showed neuroprotective properties. Choi et al. (2009, 2014) isolated 3-(hydroxymethyl)-4-methylfuran-2(5H)-one, (3R, 4S, 1' R)-3-(1'-hydroxyethyl)-4-methyldihydrofuran-2(3H)-one, 5-hydroxy-4-(1-hydroxyethyl)-3-methylfuran-2(5H)-one, and 5-phenylpentane-1,3,4-triol from *Mycleptodonoides aitchisonii*, which also exhibited activity. It has been reported that Alzheimer's disease pathogenesis includes microglial activation associated with neuroinflammation, increased level of acetyl cholinesterase (AChE) activity, and free radical generation

(Martorana et al. 2012). Brondz et al. (2007) isolated 6-hydroxyinfractine and infractopicrine (alkaloids infractine) from *Cortinarius infractus*, which showed AChE-inhibiting activity with nondetectable cytotoxicity (Geissler et al. 2010). Caruiglian C and 1-(3,4,5-trimethoxyphenyl) ethanol were isolated and purified from *Daldinia concentrica*, which showed neuroprotective activity (Lee et al. 2002b). On the other hand, it has been reported that psilocybin from the hallucinogen *Psilocybe* species showed antidepressant properties (Mason-Dambrot 2012; Kraehenmann 2015; Grob et al. 2011; Carhart-Harris et al. 2012; Petri et al. 2014). Psilocybin is a phosphate derivative of N,N-dimethyltryptamine that is present at concentrations of 0.1–1.5% in species of the *Psilocybe* genus. This compound is considered nonaddictive and rarely abused. In humans, psilocybin converts to psilocin, which is a pharmacologically active drug (Norchem 2011). The antioxidant metabolites, 2,4,6-trimethylacetophenone imine, glutamyl tryptophan, azatadine, and lithocholic acid glycine conjugate were isolated from *Boletus* spp, which exhibited antioxidant activity (Yuswan et al. 2015).

4 Future Trends

Mushrooms are functional food and are a source of biologically valuable components that offer great therapeutic potential for the prevention and control of several diseases. A large number of mushroom-derived bioactive compounds, both cellular components and secondary metabolites, have been isolated. Some studies about mushrooms' bioactivity were assayed using crude mushroom extracts or mixture of mushroom metabolites. These studies will require the isolation and identification of the bioactive compounds in order to determine the bioactive effect of each compound. Both the optimization of submerged culture conditions for mycelial growth and strain improvement by genetic manipulation are crucial in order to overproduce the desired compound. Further research and clinical trials have to be carried out to validate that mushrooms are source of bioactive molecules with medicinal application.

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