Chapter 5

The Antioxidant Potential of Some Mushrooms

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Abstract

The Fungi kingdom is one of the largest taxon in systematics with estimated 1.5 million species. With distinct lifestyles, including saprophytism, parasitism and symbiotism, members of Fungi are not only crucial for natural material cycles but also important for human health since they contain various bioactive components with antioxidant, antimicrobial, anti-tumor, and immunomodulating activities. These components can be obtained both from the mycelia or the fruiting bodies of a fungus. People have appreciated mushrooms (fruiting bodies of fungi) for their culinary qualities and unique medicinal properties since ancient times. In recent years, with increasing health concerns and growing interest in alternative treatment methods, the nutritional and health-beneficial properties of mushrooms have become more remarkable. In particular, mushroom species with high antioxidant activity contain pharmacologically valuable components and are thought to have various positive effects on human health. Better understanding the potential of mushrooms as natural resources and integrating this knowledge into clinical practice is important for developing new strategies to improve human health. This review is based on recent research conducted on various mushroom species. Mushrooms with high antioxidant activity are reported to contribute to pharmacological studies and their positive effects on health are discussed.

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1. Introduction

Around the world, many communities have utilized mushrooms for a variety of purposes. They are widely found in different ecosystems. They have an important place among natural products [1]. The use of natural resources originating from regional biodiversity has surged, given the correlation between mushrooms and improved health and quality of life. For 21st century consumers, it is thought that food is not only a source of survival and energy, but also food should be considered as medicine and medicine as food, referring to the statement of Hippocrates. Many nations acknowledge the importance of including mushrooms in diets [2]. Protein, carbohydrates, vitamins, vital amino acids, and other nutrients are among their excellent nutritional values. They are also recognized as important medicinal resources [3].

In the last decade, various traditional food products have been re-evaluated and attracted the interest of consumers in terms of health benefits. Edible and medicinal mushrooms are among the food products that can support health status, therefore consuming them has grown popular [4]. Mushrooms are widely favored for their natural ingredients and as a source of microelements and bioactive metabolites, as well as their unique aromas and flavors. The use of mushrooms in popular culinary culture has been further explored and incorporated into herbal formulas, teas and health tonics [5].

Mushrooms can be utilized as components in functional foods because they have bioactive properties. This means that fungi can serve as natural matrices, i.e. they can provide a natural framework in which functional products are contained or formed. They can also serve as valuable ingredients that can be used to fortify certain food products [6]. Mushrooms are increasingly recognized as modern health food ingredients [7]. The phenolic compounds found in mushrooms, including protocatechuic acid, catechin, caffeic acid, gallic acid, myricetin and ferulic acid, are of interest to the food and pharmaceutical industries [8]. However, because of the variety of bioactive compounds found in mushrooms, researchers in the area of biotechnology have looked at how to extract useful functional molecules from industrial waste products [9]. They have a high protein content and are also a good source of vitamins, including niacin, thiamine, ascorbic acid, riboflavin, and ergosterol [10]. The amount of protein and overall carbohydrates in mushrooms may vary based on the species and cultivation process. Protein content is usually between 15% and 35%, and total carbohydrate content is usually between 35% and 70%. Furthermore, mushrooms may contain

significant amount of fiber (chitin and β-glucans) and are considered healthy food sources with low-fat content [11]. Also, the mushrooms are known as an excellent mineral accumulator. They contain high amounts of zinc, iron, and manganese [12]. However, edible mushrooms are generally consumed either as dried products or as fresh mushrooms with fruiting bodies. The medicinal mushrooms are typically employed in powder, loose, or liquid extract forms for biopharmaceutical applications [13]. This review reports recently investigated mushrooms with high antioxidant activity and their methods, which are thought to make a great contribution to food and clinical studies.

2. Mushrooms with High Antioxidant Potential

Antioxidants are one of the bioactive components of functional foods and play a key role in combating the damage caused by free radicals, which are generally defined as high-energy and unstable molecules with one or more unpaired electrons in their structure. Cell death results from the constant generation of free radicals. Numerous illnesses, including cirrhosis, diabetes, cancer, and aging, are brought on by these cell deaths and damage. In order to avoid chronic illnesses, natural antioxidants are crucial [14].

Under normal conditions, in a healthy individual, there is a balance between nitrogen (RNS; reactive nitrogen species) free radicals or oxygen (ROS; reactive oxygen species) antioxidants that occur naturally during metabolic activities in the body [15]. In addition to various extrinsic factors such as ultraviolet rays, environmental pollution, alcohol, smoking, and aging, some intrinsic factors can also trigger free radical formation. Under the influence of these factors, the amount of free radicals, which are beneficial at low concentrations, may increase and the free radical-antioxidant balance may be disturbed. Disruption of this balance leads to oxidative stress, which is associated with many diseases such as neurodegenerative diseases, diabetes, rheumatoid arthritis, cardiovascular diseases, respiratory system diseases, and cancer [16]. Mushroom phenolics are aromatic hydroxyl compounds that possess significant antioxidant capacity. Because of their ability to bind transition metal ions and act as hydrogen donors in the formation of stabilized radicals, flavonoids are the compounds that give specific antioxidant activity in polyphenolic compounds [17].

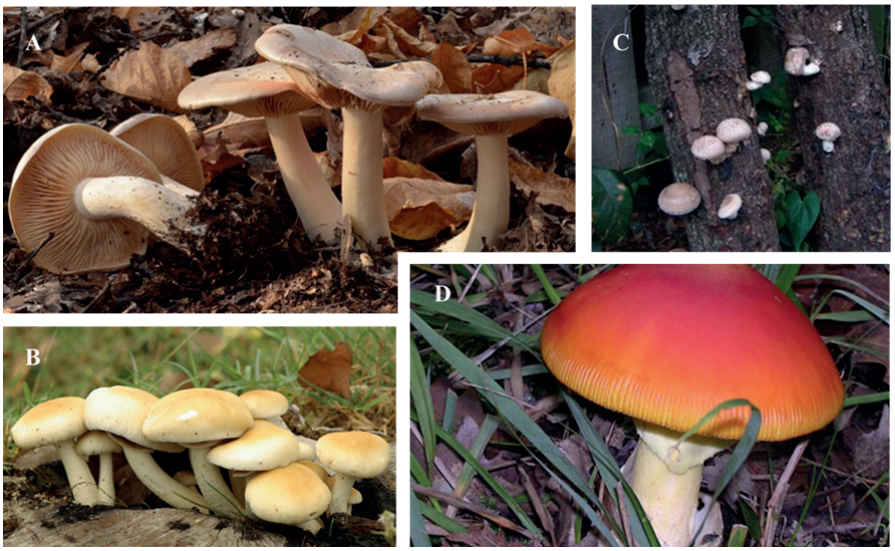

Photo 1. (A) Entoloma sinuatum (Fr.) P. Kumm. (1871) (B) Agrocybe aegerita (V. Brig.) Singer (1951) (C) Lentinula edodes (Berk.) Pegler (1976) (D) Amanita caesarea (Scop.) Pers. (1801)

***Entoloma sinuatum* (Fr.) P. Kumm. (1871):** Also referred to as leaden entoloma, lead poisoner, livid agaric, and livid pinkgill. It is a toxic mushroom that grows in North America and Europe. The outdated scientific names *Rhodophyllus sinuatus* and *Entoloma lividum* are still used in certain guidebooks. The type species of the pink spore mushroom genus Entoloma is also the largest mushroom [18].

***Agrocybe aegerita* (V. Brig.) Singer (1951):** It is referred to as "chestnut mushroom" and is a type of white rot fungus. Modern science also acknowledges the anti-inflammatory, antifungal, antibacterial, and anti-tumor effects of this mushroom. This mushroom is rich in minerals, vitamins, and phytochemicals. It has a particularly high concentration of copper and vitamin B5, pantothenic acid. In addition, it has selenium, potassium, riboflavin (vitamin B2), folate, biotin, niacin (vitamin B3). It is claimed to include substances that have the ability to block the cyclooxygenase enzyme, an enzyme that medications like Tylenol, Adril, and others are also attempting to suppress [19].

***Lentinula edodes* (Berk.) Pegler (1976):** *Lentinula edodes*, also known as Shiitake, is a species of edible mushroom recognized for its health benefits. Studies have revealed a relationship between the bioactive compounds of *L. edodes* and its antioxidant activity. It was stated that this relationship was

formed by phenolic compounds, terpenoids, ergosterols, and polysaccharides found in *L. edodes*. It is also reported that *L. edodes* has various pharmacological activities including anticancer, and immunomodulatory properties [20].

***Amanita caesarea* (Scop.) Pers. (1801):** *Amanita caesarea*, also known as "Caesar's mushroom", is a species of mushroom commonly found in Southern Europe and Asia, and has been the focus of medical research, particularly for its phenolic content and antioxidant activity. Numerous investigations on the total phenolic content and antioxidant activity of *A. caesarea* have yielded insightful data regarding its possible medical applications. A polysaccharide from *A. caesarea* has been shown in one study to have significant promise in the management of Alzheimer's disease [21].

Photo 2. (A) Clitocybe odora (Bull.) P. Kumm. (1871) (B) Lactarius deliciosus (L.) Gray (1821) (Photo by Krisp H.) (C) Russula vinosa Lindblad (1901) (D) Tricholoma imbricatum (Fr.) P. Kumm. (1871)

***Clitocybe odora* (Bull.) P. Kumm. (1871):** *Clitocybe odora* (Bull.) P. Kumm (Agaricales) is a species of fungi that are abundant in forests dominated by pine trees and broadleaved forests. They have the ability to spread widely from late summer to early spring. This is an edible mushroom species. However, over consumption may lead to gastrointestinal syndromes [22].

***Lactarius deliciosus* (L.) Gray (1821):** The name Lactarius originates from the secretion of a milky white cellular fluid known as lactate when fruiting bodies are damaged or cut. *Lactarius deliciosus* is an ectomycorrhizal fungus of great importance for the growth of pine forests. *L. deliciosus*, also known as pine mushroom or saffron milk cap, forms a mycorrhizal association with its host and grows in acidic soil under coniferous forests [23]. The flesh of the fruiting body of *L. deliciosus* is flavourful, tender, and nutritious. As a medicinal and edible mushroom species, *L. deliciosus* is widely studied for its bioactive substances such as polysaccharides and proteins [24].

***Russula vinosa* Lindblad (1901):** *Russula vinosa* is an edible and nutritious mushroom containing a range of bioactive compounds including polysaccharides, proteins, trace elements, vitamins and amino acids. *R. vinosa* is a versatile edible fungus that is used in many different recipes due to its distinct flavor and excellent nutritional and therapeutic value. Frequently, polysaccharides in *R. vinosa* are heteropolysaccharides containing glucose, galactose, mannose and xylose which exhibit antitumour, antioxidant, immunomodulatory and hepatoprotective biological activities. Antitumor, anti-aging, and anti-inflammatory bioactivities of *R. vinosa* are promising. For *R. vinosa* species, it was reported that water-soluble and alkali-soluble polysaccharides from fruit bodies may protect the liver from CCl4-induced hepatic damage through antioxidant mechanisms [25, 26].

***Tricholoma imbricatum* (Fr.) P. Kumm. (1871):** It grows on sandy soil in pine forests, especially on acidic soils. As a result of research on Tricholoma species, it has been determined that these species generally contain many secondary metabolites including terpenoid derivatives. In phytochemical studies, terpenoids found in Tricholoma species were defined as components such as diterpenes, triterpenes, polyoxidised steroids, phenolic monoterpenoids, dieningeranyl cyclohexenones and other indole derivatives with high antioxidant activities [27, 28].

Photo 3. (A) Lycoperdon perlatum Pers. (1795) (B) Laetiporus sulphureus (Bull.) Murrill (1920) (C) Suillus collinitus (Fr.) Kuntze (1898) (D) Morchella esculenta (L.) Pers. (1801) (E) Cordyceps militaris (L.) Fr. (1818)

***Lycoperdon perlatum* Pers. (1795):** *Lycoperdon perlatum*, also known as puff mushroom, which belongs to the family Agaricaceae, can live in almost every habitat, and can be found singly or in clusters. It has no lamellae and the cap is whitish in color. Although it is usually seen in the autumn months, it is possible to see it throughout the year. It is usually seen in forests with pine species. Studies have demonstrated that water and methanol extracts of this species have high antioxidant activity [29].

***Laetiporus sulphureus* (Bull.) Murrill (1920):** The fruiting bodies of *L. sulphureus*, also known as sulphur mushroom, have been the subject of many studies. According to reports, it can "induce diuresis, drain dampness, invigorate the spleen and calm the mind" when used in traditional Japanese and Chinese medicine [30].

***Suillus collinitus* (Fr.) Kuntze (1898):** Suillus is a mushroom genus from the Suillaceae family, popularly known as bear mushroom, which grows individually or in groups from summer to autumn in calcareous soils under pine. The genus Suillus contains a phenolic acid called "suillinin" and this phenolic substance has been proven to be a strong inducer of apoptosis in human hepatoma HepG2 cells [31]. It was also reported that the methanolic extract obtained from *S. collinitus* caused apoptosis in breast cancer cells [32].

***Morchella esculenta* (L.) Pers. (1801):** *Morchella esculenta* is one delicious mushroom distinguished for its special tastes and potent health

promoting abilities [33]. It is called the golden morel because of its golden color. It is found in pine forests in our country. It is seen in the spring season. Nutritionally, like many other edible mushrooms, the main compounds found in *M. esculenta* include polysaccharides, free amino acids, proteins, fatty acids, polyphenols, mineral substances, and alkaloids. According to the results of research conducted with this mushroom species, it has been determined that *M. esculenta* has antioxidant, antimicrobial and immunomodulatory properties [34].

***Cordyceps militaris* (L.) Fr. (1818)**: *Cordyceps militaris*, one of the most important medicinal fungi belonging to the order Ascomycetes, is known as a parasite of Lepidoptera insect larvae. *C. militaris* hifleri pupaların içinde normal şekilde büyür ve ölür ve daha sonra pupaların başından, göğsünden veya karnından çıkar [35]. It is used as a traditional medicinal drug, especially in East Asia [36]. C. militaris'in biyoaktif bileşenleri arasında cordycepin asit, mannitol, alkaloidler, cordycepin, B1 ve B2 vitaminleri ve polisakkaritler bulunur [37]. Toplam ağırlıklarının %3-8'ini oluşturan C. militaris'teki polisakkaritler, birincil aktif bileşiklerdir ve kan şekerini düşürücü, antioksidan, bağışıklık sistemini güçlendirici, antitümör, antibakteriyel ve antiinflamatuar etkiler gösterir [38].

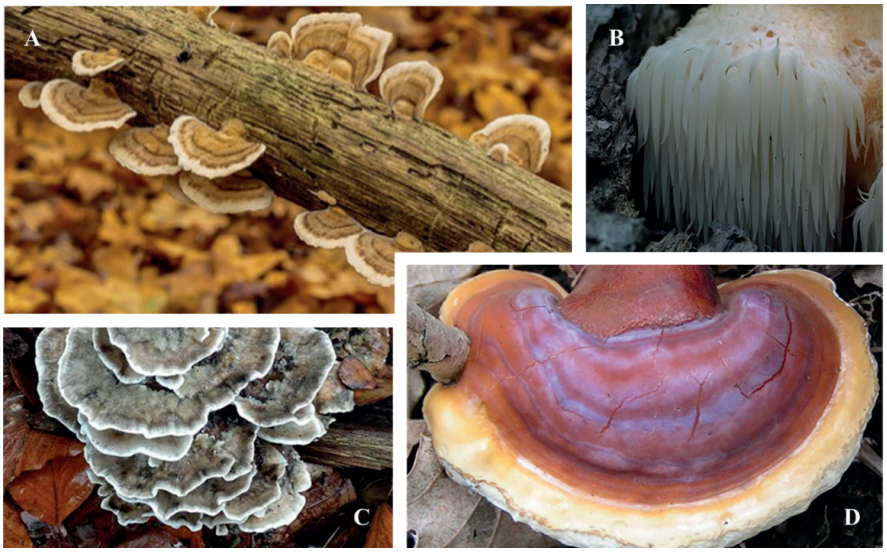

Photo 4. (A) Trametes versicolor (L.) Lloyd (1920) (B) Hericium erinaceus (Bull.) Pers. (1797) (C) Bjerkandera adusta (Willd.) P. Karst. (1879) (D) Ganoderma lucidum (Fr.) P. Karst. (1881)

***Trametes versicolor* (L.) Lloyd (1920):** Also known as the turkey tail mushroom. It is a fungus easily found in wooded areas in Europe and China, and is the most common polypore in the oak forests of the Pacific Coast in the USA [39]. It has been observed that the Trametes mushroom increases the synthesis of P53 protein that provides cell death and decreases the synthesis of Bcl-2 proteins that inhibit cell death. Trametes mushroom accelerates the death of cancer cells by improving the defective apoptosis mechanism of cancer cells [40].

***Hericium erinaceus* (Bull.) Pers. (1797):** Commercially grown *Hericium erinaceus*, often known as "Lion's Mane," is a significant edible and medicinal mushroom species that is extensively consumed in Asian nations due to its advantageous nutritional and health properties. It has an extended history in conventional Chinese medicine as well. This species can aid in the mitigation, prevention, and even therapy of a number of grave health issues, including diabetes, cancer, depression, and neurological disorders [41]. *H. erinaceus*'s primary active ingredients are polysaccharides, steroids, alkaloids, lactones, terpenoids (particularly species-specific ones like erinacines and hericenones), and a few phenolic compounds. These substances contribute to the stimulation of neurogenesis, promote learning and memory processes, have anticancer activity, and modulate the immune system, among other functions of the nervous system [42].

***Bjerkandera adusta* (Willd.) P. Karst. (1879):** *Bjerkandera adusta* is a white rot fungi belonging to the Meruliaceae family. Like many other white rot fungi, it plays a role in lignin degradation and mineralization by secreting ligninolytic enzymes (such as manganese peroxidase, laccase and lignin peroxidase). These enzymes also contribute to the prevention of environmental pollution by providing color removal in dye and textile wastewater [43].

***Ganoderma lucidum* (Fr.) P. Karst. (1881):** *G. lucidum* is one of the medicinal mushroom species that is particularly valuable in cancer treatments due to its anti-inflammatory effect, immune-boosting properties, and toxic effect against cancer cells. *G. lucidum* polysaccharides are the main active components of the water-soluble extracts. These polysaccharides are known to prevent cancer cells from forming a new vessel and stop the development of tumour cells by showing direct cytotoxic effect [44]. Mushrooms with high antioxidant activity in studies conducted in the last four years are listed below. Methods and results are reported in Table 1.

Table 1: Research conducted on antioxidant activities of various macrofungi by different methods.

Mushroom Type	Extraction Solvent	Antioxidant Activity Method	Activity Result	Reference
Agrocybe aegerita	%60 Ethanol	ABTS radical scavenging	1981 mg TE/100 g	[45]
Amanita caesarea	Methanol	DPPH radical scavenging IC50 (mg/mL)	0.15±0.02	[46]
Bjerkandera adusta	Ethanol	DPPH radical scavenging	200 mg/mL 79.66%	[47]
Clitocybe odora	Ethanol	Rel Assay TAS (μmol H_2O_2 equivalent L^{-1})	6.801±0.243 mmol/L	[48]
Cordyceps militaris	Methanol	DPPH radical scavenging IC50 (mg/mL)	0.97±0.08 and percentage inhibition: 45.79-91.58	[46]
Coriolus versicolor	Ethanol	DPPH radical scavenging (μM TE/g)	39,16±0,82	[49]
Entoloma sinuatum	Ethanol	Rel Assay TAS/ TAS (mmol/L)	2,64±0,15	[50]
Ganoderma lucidum	Methanol	DPPH radical scavenging	Scavenging activity of 90.81%	[51]
Hericium erinaceus	Methanol	DPPH radical scavenging (μM TE/g extract)	38.88±1.59	[52]
Laetiporus sulphureus	Methanol	DPPH radical scavenging (IC50 μg/mL IC50 equivalent 5.33 mg/mL)	15.83 - 61.03%	[53]
Lentinus edodes	Methanol	DPPH radical scavenging	984.4 mg TE/100 g	[45]
Lycoperdon perlatum	Aqueous extract	DPPH radical scavenging	60.3% scavenging activity	[54]
Macrolepiota procera	Methanol	DPPH radical scavenging IC50 μg/mL	215.03±5.63	[55]

Morchella esculenta	Methanol	DPPH radical scavenging	82.25 μg/mL-40.8% scavenging activity	[56]
Russula vinosa	polyphenol-rich extract (80%methanol)	DPPH radical scavenging	90% and above scavenging activity	[57]
Suillus collinitus	Ethanol	Rel Assay TAS/ TAS (mmol/L)	2.467 ± 0.145 mmol/L	[58]
Suillus luteus	%60 ethanol	ABTS radical scavenging	2211 mg TE/100 g	[45]
Tricholoma imbricatum	Ethanol	Rel Assay TAS/ TAS (mmol/L)	3.474±0.049	[59]

Table 1 shows that the results obtained from various studies differed. The reasons for the different results may include the cultivation methods, development of the mushrooms under different environmental conditions, developmental stages during harvesting and genetic diversity among species. Some other examples about the antioxidant activity of various mushroom species are mentioned below to support this statement.

According to a study, Russula virescens ethanol and aqueous extracts demonstrated dose-dependent DPPH radical scavenging ability. Hasnat et al. [60] reported that the ethanol extract had the most scavenging activity at 52.62%, whereas the aqueous extract had the highest activity at 81.13%. In another study investigating the DPPH scavenging activity of Ganoderma lucidum, the scavenging activity of 200 mg/mL mushroom extract against 0.1 mM DPPH solution was determined as 90.81%. This value is quite high compared to other medicinal mushrooms. The DPPH scavenging activity determined in this study is consistent with other studies conducted with Ganoderma species [51].

According to Kalyoncu et al. [61] the ethanol extract of Morchella esculenta var. rigida shown a scavenging activity of 87.07% against ABTS+ radicals, but the ethanol extract of Omphalotus olearius demonstrated a considerably high scavenging activity of 88.01% against the same radicals at a concentration of 1 mg/mL. The methanol extract of *Morchella conica* (40 μg/mL) showed 78.66% scavenging activity against ABTS+ radicals [62]. The methanol extract of *Amanita cesarea* at 0.14 mg/mL concentration showed 92.0% scavenging activity against ABTS+ radicals [63]. Keleş et al. [64] reported that the methanolic extract of *Suillus luteus* at a concentration of 25 mg/mL showed the highest (97.96%) scavenging potential in a

study reporting the scavenging potential of some fungal species. Ethanol extract of Bjerkandera adusta showed 79.66% scavenging activity against 0.1 mM DPPH solution [47]. In a study examining the DPPH radical scavenging activities of *Clitocybe geotropa*, *Amanita caesarea*, *Lentinula edodes* and *Cordyceps militaris* it was found that *A. caesarea* and *C. militaris* showed higher antioxidant activity [46]. This study serves as a resource for the potential use of these mushroom species in alternative medicine.

3. Conclusion

This review highlights the great potential of mushrooms for health and shows the importance of 20 different mushroom species with high antioxidant activity. Antioxidants reduce oxidative stress and protect cellular health by neutralizing the harmful effects of free radicals in the body. These antioxidant properties in mushrooms offer an important contribution to health. These wild mushrooms, which are used both as food and medicine and constitute an important source of antioxidant compounds, may have medicinal value due to their antioxidant activity.

In particular, the antioxidant activities of a wide range of mushroom species from Agrocybe aegerita to Cordyceps militaris, Lentinula edodes to Tricholoma imbricatum have been studied. Many of these species are also known to be used in traditional medicine and are supported by modern research. The antioxidant properties of mushrooms are especially important in combating oxidative stress, which increase due to the stress of modern life, environmental factors and poor dietary habits. Therefore, this study highlights the positive effects of mushrooms on health and points the way for future research. Future research is needed to better understand the biological effects of these mushrooms and to evaluate their potential therapeutic uses. This study may open new avenues for the utilization of antioxidant-rich mushrooms in the health industry and nutrition.

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