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A review of mushroom cultivation and production, benefits and therapeutic potentials

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Abstract

The purpose of this paper is to review and evaluate published literature on mushroom cultivation and production and the range of benefits and therapeutic potential. A systematic method was used to gather the relavant literature. A total of twenty-six research papers published between the years 1970 to 2022 were selected and utilized in this review. Tables were used to present the results and relevant figures were used to place emphasis on contents discussed. In this paper five (5) benefits and nine (9) therapeutic potentials were evaluated and reported on. Some medicinal mushrooms and their uses and bioactive compounds were also discussed in this paper. Additionally, mushroom cultivation and production was addressed as well as challenges associated with mushroom farming and an assessment of their nutritional content compared to other food consumed by humans. The published papers established that mushrooms have been massed produced and harvested for a long time and their benefits are well documented in countries outside the neotropics. More studies to investigate the uses of mushrooms should be done, in Guyana and other neotropical countries as there is a paucity of information in this region with high natural biodiversity.

Keywords: Mushrooms; Cultivation; Production; Benefits; Therapeutic potential

1. Introduction

Until very recently, the Fungi were thought to be part of the Plant Kingdom, but they are now understood to be a completely different and unique group of organisms. Most fungi, with the exception of a few, have clearly defined cell walls that all of their nutrients must pass through in a soluble state. In this way, they vary from mammal cells, which have ill-defined cell walls [211] [251] [285].

Although it is speculative, new estimates strongly indicate that there may be well over 1.5 million different species of fungi [211] [251] [285]. The fungi differ greatly in terms of their size, structure, and metabolic processes. While most fungi exist as microscopic filaments or hyphae that stretch at the tip, branch, and fuse (anastomose) to form a complex mycelium or network, the tiniest, like yeasts, grow as loose clumps of single unattached microscopic cells. These mycelial networks become visibly more prominent as they grow in size. Large fruit bodies commonly referred to as mushrooms are an example of how the mycelia may produce complex, elaborate structures [211] [251] [285].

The bulk of fungal species, by virtue of their apical growth patterns, are better adapted to growth over and through solid surfaces, especially in terrestrial habitats, even if many do grow and operate in watery conditions. Fungi play a significant role in the soil environment by decomposing decaying organic waste, but they can also spread widely in humans, animals, and other living things, leading to disease and degradation. On the one hand, fungi play a significant

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role in biotechnology, in the production of wines, beers, spirits, fermented food products such as cheeses, antibiotics, industrially significant organic acids, and now many important medicinal compounds. On the other hand, many fungi attack manufactured products, including foodstuffs, fabrics, leather, timber, cosmetics, pharmaceuticals, aviation fuel, etc. Numerous edible mushrooms alone are the foundation of many commercial processes [211] [251] [285].

The welfare of humans has been greatly influenced by mushrooms, one of the most diverse organisms on the planet. In the taxonomy of fungi, a mushroom is the fleshy, spore-bearing fruiting body that is developed above the earth on soil or on the food substrate of the fungus [88] [201]. Mushrooms belong to the class Basidiomycetes within the order Agaricales. Since antiquity, mushrooms have been utilized by many cultures for food and medicine due to their enticing flavor, taste, dietetic benefits, and several therapeutic capabilities [88] [201] [233] [143]. Over the years, better and more efficient techniques have subsequently been developed and used to greatly increase mushroom production [144]. There is a process of sexual reproduction in both the Basidiomycetes and Ascomycetes that begins in the underground mycelial stage and eventually manifests in the huge above-ground macroscopic meaty fruit-bodies, or mushrooms [211] [251] [285].

The main purpose of these mushroom structures, which come in a variety of shapes and hues, is to disperse the spores or units of propagation. The final mechanism of sexual spore release is where the two types diverge the most. The Ascomycetes are frequently referred to as "sac fungi" because they generate sac-shaped capsules (the asci) inside the mushroom mass that actively release spores into the atmosphere for wind dispersal. In contrast, the Basidiomycetes, also known as "club-fungi," produce spores that are linked to basidia, or structures that resemble clubs (Figure 1).

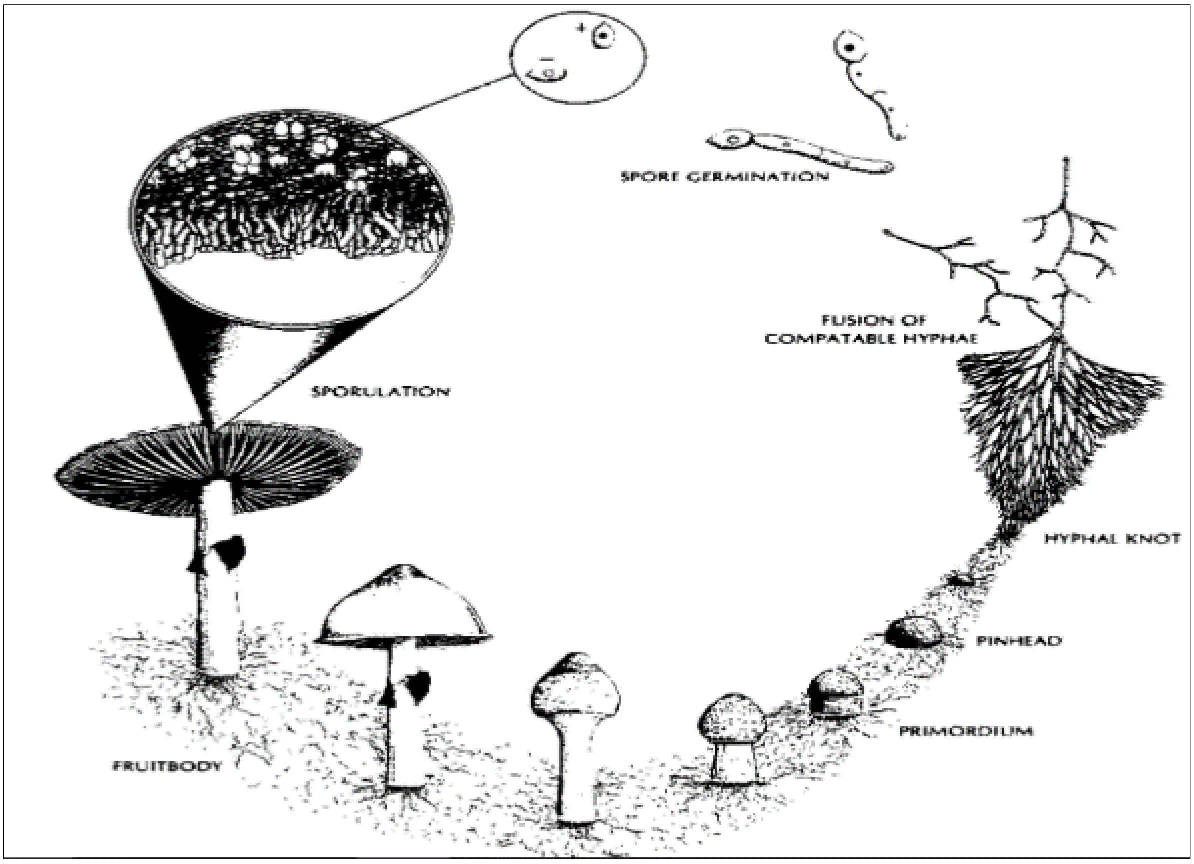

Figure 1 The lifecycle of the Basidiomycete mushroom (Stamets, 2000; Smith *et al.*, 2002)

2. Material and Methods

The topic of "benefits and therapeutic potential of mushrooms" was the subject of a systematic review using "Google Scholar," a web-based search engine which provides a quick and easy way to search and access published articles, journals and books. Thematic keywords such as mushrooms, cultivation, production, therapeutic potential, benefits, were used in the search.

The subjects that were investigated were chosen using an approach that involved looking at the related literary works. Only publications from the years 2000 to 2022 could be acquired. Not all of the articles that were received, however, were used in this study because the major objective was to assemble data from recent research (past 10 to 20 years) on mushroom cultivation and production, benefits and therapeutic potential. However, papers from as far back as the 1970's and the 2000's that contained pertinent literature were also utilized. The search yielded various results: Some articles had all the thematic keywords and some were obtained that were specific to mushroom cultivation and production and others to their benefits and therapeutic potential. Twenty-six (26) research articles were used in total for this review.

3. Results

When searching "Google Scholar" for information on mushroom cultivation and production, benefits and therapeutic potentials, a total of 4,230,000 was retrieved. Among the results obtained from the search, a total of 79,700 were published within the years 2000-2023, 64,000 were published between the years 2010-2023 and 71,200 were published within the years 2015-2023. 74,600 publications within 2010-2023 reviewed mushroom cultivation and production and 41,100 reviewed benefits and therapeutic potential of mushrooms.

However, not all the results retrieved for this research focused on mushroom cultivation and production and their benefits and therapeutic potential. Some focused solely on mushroom cultivation and production, while others focused on mushroom genetics and their molecular biology. Others focused on the benefits of mushroom and some on the therapeutic potential of mushrooms. In addition, some papers focused on the nutritional content of mushrooms and the bioactive compounds found in mushrooms.

4. Discussion

4.1. Psychoactive, Medicinal, Poisonous and Edible Mushrooms

One of the most significant aspects is the growing understanding that many mushrooms contain a Pandora's box of intriguing medicinally significant substances. Some mushrooms are valued by the epicure, while others are avoided as they reportedly contain some of the deadliest of poisons (Table 1) [211] [251] [285].

Mushrooms have been valued as a unique category of nutrient-rich food since the dawn of mankind. Romans believed that mushrooms were the "Food of God," while the Greeks saw them as a resource that gave warriors strength in battle. Mushrooms were traditionally harvested from their natural growing environments, but over time, many attempts have been made to domesticate mushrooms in carefully regulated environments. More than 2,000 edible fungal species have been widely accepted for human consumption, but only a small number of them are commercially grown worldwide. In India, only five mushroom species are commonly grown: *Agaricus bisporus, Pleurotus species, Volvariella volvacea, Calocybe indica*, and *Lentinula edodes* [144].

The ability of mushrooms to convert necessary input into nutrient-dense, high-protein meals has led to their reputation as one of the world's finest natural resources. The mushrooms provide a good supply of nutrition in the event that a significant population rise causes a shortage of nutrient-dense foods. This is because they are a good source of minerals and vitamins. The button mushroom (*Agaricus bisporus*), paddy straw mushroom (*Volvariella* spp.), and oyster mushroom (*Pleurotus* spp.) are the three types of mushrooms now being grown around the world. The majority of *Agaricus bisporus* cultivation takes place on a commercial basis. Most processed forms of mushrooms are traded internationally [144].

The many important medicinal properties of mushrooms, which have long been valued for their culinary and nutritional value, are now being recognized as well worth valuing. As a result, they are now used not only as dietary food (functional foods), but also as dietary supplements, nutraceuticals, and mycotherapy products [84] [315] [329]. The fresh mushroom has a moisture content of 85–90%, a protein content of 3%, a carbohydrate content of 4%, a fat content of 0.3-0.4%, a mineral and vitamin content of 1%, and certain medical characteristics like decreasing cholesterol, cancer prevention, and promoting hair growth [88] [209]. Niacin, riboflavin, vitamin D, vitamin C, and vitamin B complex are among the vitamins abundant in edible mushrooms [7] [88]. To help developing nations, where a substantial portion of the population relies mostly on cereal crops, satisfy their protein needs, the FAO has advised edible mushrooms [88] [315] [335].

Table 1 Some Main Psychoactive, Medicinal, Poisonous and Edible Mushrooms found in Britain

Psychoactive Mushrooms	Medicinal Mushrooms	Poisonous Mushrooms	Edible Mushrooms	
Scientific Name	Scientific Name	Scientific Name	Scientific Name	Common Name
Lycoperdon spp.	*Trametes (Coriolus) versicolor*	*Amanita phalloides*	*Agaricus compestris*	The field mushroom
Psilocybe spp.	*Flammulina velutipes*	*Amanita virosa*	*Boletus edulis*	Cep
Paneolus spp.	*Ganoderma lucidum*	*Amanita pantherina*	*Cantharellus cibarius*	Chanterelle
Gymnopilus	*Grifola frondosa*	*Inocybe patouillardii*	*Coprinus comatus*	Shaggy inkcap
Conocybe spp.	*Hericium erinaceous*	*Cortinarius speciosissimus*	*Cratarellus cornuopiodes*	Horn of Plenty
Amanita muscaria	*Lentinus edodes*	*Cortinarius orellanus*	*Hydnum respondum*	Hedgehog fungus
Amanita pantherina	*Schizophyllum commune*	*Gyromitra esculenta*	*Laetiporus sulphureus*	Chicken of the Woods
***	*Tremella fuciformis*	***	*Lepiota procera*	Parasol mushroom
***	*Poria cocos*	***	*Lepiota saeva*	Field blewit
***	*Auricularia auricula*	***	*Marasimus oreandes*	Fairy Ring Champignon
***	***	***	*Morchella esculenta*	Morel
***	***	***	*Sparassis crispa*	Cauliflower fungus
***	***	***	*Tuber aestivum*	Truffle

(Result adopted from Philips, 1994; Miles & Chang, 1997 & Smith *et al.*, 2002)

The production of mushrooms is an environmentally beneficial, financially successful, but labor-intensive agribusiness [45] [88]. Mushrooms are an organic vegetable. It can be grown vertically in a small space without the need for any cultivable area. By producing a quick-yielding, wholesome food source and a steady source of income, mushroom farming can boost livelihoods and lessen vulnerability to poverty [88] [200]. Many locations throughout the world have commercial mushroom farms. On organic substrates rich in cellulose, hemicellulose, and lignin, such as sawdust, leaves, and other agricultural leftovers, mushrooms can be cultivated with ease [88] [205] [232] [315].

More than half of the population in Bangladesh has been malnourished, which raises serious concerns about their nutritional state [88] [126]. Because they produce in big amounts quickly and supply more protein per unit area than any other crop, mushrooms have the potential to partially alleviate the suffering caused by starvation [88] [108]. To improve national health, crop diversification and dietary changes are essential [75] [88]. The demand for and consumption of mushrooms is rising daily, and the majority of producers and sellers of mushrooms and goods made with mushrooms are small business owners [88] [269].

Wool and other natural fibers can be dyed with the help of mushrooms. Mushroom chromophores produce intense, vivid hues, and mushroom dyes can produce any color in the spectrum. The principal source of textile dyeing prior to the development of synthetic colors was mushrooms. Tinder fungus are mushrooms that have been used to start fires. The criminic and oysters are used to clean up the environment. Mycelium is used in the process known as myco-remediation to break down pollutants like petroleum, fertilizers, pesticides, explosives, and industrial, medical, and agricultural wastes [144].

4.2. Mushroom Cultivation and Production

The first mushrooms were produced in India in the 1970s, but as environmental control technology and a better understanding of cropping systems have evolved, mushroom output has increased significantly [144]. Following oyster (6%), milky (1%), and other (4%), button mushrooms made up 89% of all the mushrooms produced in India in 2010. A total of 94,676 metric tons of white button mushrooms are now produced in India from both seasonal and high-tech cultivation units, and they account for roughly 73% of the country's total mushroom production [144].

The mushroom industry in the United States (U.S) generated $1.22 billion in revenue in 2017. Since 2007, this indicates an 8% gain in value. The crop's total weight was 929 million pounds, a 2 percent decrease from the year before but a 12 percent (12%) gain over the preceding ten years. Around 60 % of all mushroom sales are produced in Pennsylvania, a percentage that has not changed over the past ten years. The industry is consolidating at the same time that production value is rising. The industry is consolidating at the same time that production value is rising. Between 2007 and 2017, the number of *Agaricus* and specialist mushroom growers fell by 32%. Growers have increased production through acquiring already-existing operations, extending their own operations, and both constructing new production facilities and improving their already-existing operations [23] [80].

Although commercial production of mushrooms began in Europe at the turn of the century, Bangladesh has only recently begun to produce them. Twenty different types of mushrooms, of which 5–6 are poisonous, are produced in the wild in the nation (Table 2). The oyster (*Pleurotus* spp.) and white button mushroom (*Agaricus bisporus*) are the two species that are most suitable for cultivation [32] [88]. Due to its good environment, cheap production costs, accessibility to growth substrates, and high market value, Bangladesh is one of the most suited countries in the world for mushroom farming [88] [123] [311]. Although there is a great potential for mushroom production in Bangladesh, there are several issues with cultivation and marketing that must be resolved before actions can be taken to increase production [88] [254].

Table 2 Mushroom cultivars and their species

Scientific Name	Mushroom Species	Variety Name	Features
Pleurotus spp.	Oyster	NOM-1 (NAMDEC Oyster Mushroom 1), NOM-2, NOM-3, NOM-4, NOM-5, and NOM-6	Biological efficiency (BE) more than 100% and can grow throughout the year
Lentinus edodes	Shiitake	NAMDEC Shiitake Mushroom 1	High nutritional and medicinal value, BE more than 70%
Ganoderma lucidum	Reishi	NAMDEC Reishi Mushroom 1	High medicinal value and BE 28%
Calocybe indica	Milky White	NAMDEC Milky Mushroom 1	Very nutritious and tasty mushroom, BE 100%
Agaricus bisporus	White Button	*****	High value mushroom and grown in winter, BE 13%
Volvariella volvacea	Straw	*****	Grown in summer season and BE 30%
Auricularia auricula	Wood Ear	*****	Year-round and rich in iron, protein and vitamins B_1 and B_2
Flammjlina flutes	Enoki	*****	Highly rich in vitamins and minerals
Hericium erinaceus	Monkey Head	*****	High medicinal value can improve nervous system

(Result above adopted from Sarker, 2019; Sarker, 2020; Mushroom Development Institute, 2019 & Ferdousi *et al*., 2020).

Due to people's unfavorable attitudes and their misconception that mushrooms are Halal, they have not received much attention as a dietary item in Bangladesh [79] [88]. Although mushroom cultivation technique is a relatively new development, incorporating this unconventional crop into the current agricultural system can help to improve the social and economic status of rural farmers and suburban residents. In 2014, the government of Bangladesh built the Mushroom Development Institute (MDI), formerly known as the National Mushroom Development and Extension Centre (NAMDEC), in Saver, Dhaka, to provide training and promote mushroom farming [88].

The Bangladeshi population is becoming more and more interested in producing and eating mushrooms. Its production in Bangladesh is rising daily, as seen by the nearly four times bigger number of mushrooms produced in 2018–19 compared to 2009–10. Over the past ten years, a nascent trend in mushroom production has been seen. Through the use of low-cost, farmer-friendly equipment and MDI-developed technology, mushroom output and consumption are rising in Bangladesh [88] [268]. Although Bangladesh's mushroom production has expanded, the demand has not yet been met. It is projected that importing mushrooms would cost the nation BDT 85 to 90 crore annually [88] [304]. There are more than 10 million tons of mushrooms produced worldwide [88] [90] [201], however only 0.04 million tons come from the nation. More than 25 districts in Bangladesh are home to commercial mushroom farming [79] [88]. Among Bangladeshi rural farmers, small-scale mushroom farming is expanding using a variety of production methods. There were observable differences in the monthly production of mushrooms in 10 farms of various sizes. Despite the larger farm's (32 sq ft) size, the difference in management style may be the cause of the smaller farm's (15–30 sq ft) higher output efficiency.

The Netherlands now produces 270 million kg of mushrooms annually and supports more than 10,000 jobs, making it the largest mushroom-producing nation in the EU. The Netherlands is third in the market behind the United States and China. With a market share of 70%, China has the highest production of mushrooms among the top ten producing countries, followed by Italy (10.16%) and the United States (5.29%). Around the world, millions of tons of mushrooms are grown annually. However, Poland was the world's top exporter of mushrooms. The Netherlands topped the list of leading mushroom eaters in terms of consumption, with 11.62 kg per person annually. In China, Japan, Poland, and India, the average annual consumption of mushrooms was less than one kilogram [144].

4.3. Socio-economic Status of Mushroom Growers

The production of mushrooms is primarily done by local people and even specialists around the world. According to a study on mushroom growers in the Savar upazila, the percentage of women involved in the production of mushrooms is exceptionally high (82.6%). The study also revealed that 31.4% of farmers engaged in mushroom farming as a supplementary employment, while 68.6% of farmers chose it as their major occupation [88] [269]. Small-scale mushroom farming was found to need relatively little investment, which resulted in low daily production, with 80% of farms producing only 1–5 kg and the remaining 20% producing 5–10 kg [88].

4.4. Challenges of Mushroom Production

Although growing in popularity among farmers, there are several issues that are causing the production of mushrooms to stagnate (Table 3).

Table 3 Issues that affect mushroom production

Problems During Production	Problems During Marketing
Lack of cultivation house.	Lack of available markets.
Capital crisis.	High transportation cost.
Insects attack (flies and cockroach).	Large number of middlemen.
Lack of the availability of quality spawn.	Very limited wholesale market.
High price of raw materials.	Unknown product to general consumers.
Lack of equipment's (Air conditioner, sterilization chamber, Water tank, Steel rack etc.).	Lacking of advertising.
High temperature in summer.	Absence of storage facilities.
Lack of trained and experienced labour.	*****
Heavy rainfall during monsoon.	*****
Very low temperature in winter.	*****
Time maintaining.	*****
Inappropriate timing of production.	*****

(Result above adapted from Ferdousi *et al.*, 2020).

4.5. Nutritional Benefits of Mushrooms

It is widely known that mushrooms include all the necessary elements of a balanced diet. Table 4 illustrates how the nutritional value of mushrooms differ by species. The truth is that mushrooms are high in easily digested essential amino acids, abundant protein, vitamins, and minerals, but deficient in high-quality unsaturated fat and water-soluble carbohydrates [38] [88] [200]. Additionally, it is abundant in other crucial elements like phosphorus, potassium, calcium, copper, iron, and the vitamin B complex [88] [130].

The mineral composition of various mushroom species also varied. In 2009, Khan *et al.*'s analysis of the mineral content of various mushroom species revealed that per 100 g of dried mushrooms, there were 15.4-69 mg Fe, 16-275 mg Ca, 11.1-28.8 mg Zn, 14-31.4 mg Mg, and 685-1740 mg P. Different mushroom species have metabolizable energy contents that range from 150 to 300 Kcal per 100g of dry mushroom [88] [152]. Depending on species, the nutritional index of mushrooms ranges from 6 to 31, indicating a good nutritious value of this meal. The nutritional index of mushrooms in comparison to other foods is represented on Figure 2. Edible mushrooms generally have fewer calories and fat than other plant-based foods, are high in vitamins, minerals, and protein [16] [88] [253].

Table 4 Different species of mushroom and their various nutrient contents

Mushroom spp.	Moisture (%)	Drymatter (%)	Dry weight basis (g/100 g of mushroom)				
			Protein	Lipid	Carbohydrate	Fiber	Ash
A. bisporous	89.4	10.6	37.6	10.0	23.6	21.2	7.8
P. ostreatus	89.4	10.6	28.4	4.7	35.4	21.8	8.6
P. citrinopleatus	88.0	12.0	30.3	3.4	33.1	22.2	11.0
P. eryngii	85.0	15.0	23.5	11.9	29.9	25.8	8.9
C. comatus	90.5	9.5	24.2	7.3	32.1	27.9	8.5
H. ulmarius	87.1	12.9	31.3	1.0	49.9	8.6	9.2
A. aegerita	91.4	8.6	27.6	5.4	28.7	26.7	11.6
A. polytricha	85.0	15.0	18.3	2.0	18.9	50.0	10.8
V. volvacea	89.1	10.9	20.0	10.8	42.0	15.2	12.0
L. edodes	78.5	21.5	27.0	7.2	21.7	38.3	5.8
G. lucidum	70.2	29.8	26.4	2.7	12.8	51.5	6.5
C. versicolor	58.2	41.8	26.0	3.7	9.2	50.1	11.0

(Result above adapted from Ahmed *et al.*, 2009; Khan *et al.*, 2009 & Ferdousi *et al.*, 2020).

Since mushrooms contain all the nutrients a person needs in the right amounts, they are regarded as a full, healthy diet that is excellent for all age groups, from children to the elderly. Numerous variables, such as the mushroom's species, variety, developmental stage, and ambient conditions, have an impact on its nutritional content [144]. Mushrooms are a good source of vitamins, minerals, dietary fiber, and protein. Dietary and fermentable fibers make up the majority of the carbohydrates; starch and sugars make up a little part of the total carbohydrates. Ethionine and cysteine-amino acids that contain sulfur-are in short supply in edible mushrooms, which are rich in theronine and valine-based proteins but lacking in other amino acids. Another benefit is the low lipid level, which has no cholesterol and a larger percentage of polyunsaturated fatty acids. Ergosterol, which is found in mushrooms, is a precursor for the body's production of vitamin D [144].

A mushroom's vitamin D level is influenced by postharvest management, particularly accidental sun exposure. The US Department of Agriculture gave proof that mushrooms that have been exposed to UV light contain significant quantities of vitamin D. Ergosterol in mushrooms, even after harvest, is transformed to vitamin D2 when exposed to ultraviolet (UV) light. This process is being employed consciously to produce fresh vitamin D mushrooms for the functional food supermarket market. Researchers conducted a thorough analysis of the safety of producing vitamin D in fresh mushrooms, demonstrating that artificial UV light technologies were just as effective at producing vitamin D as mushrooms that were exposed to natural sunlight. UV light has a long history of being used safely to produce vitamin D in food [144].

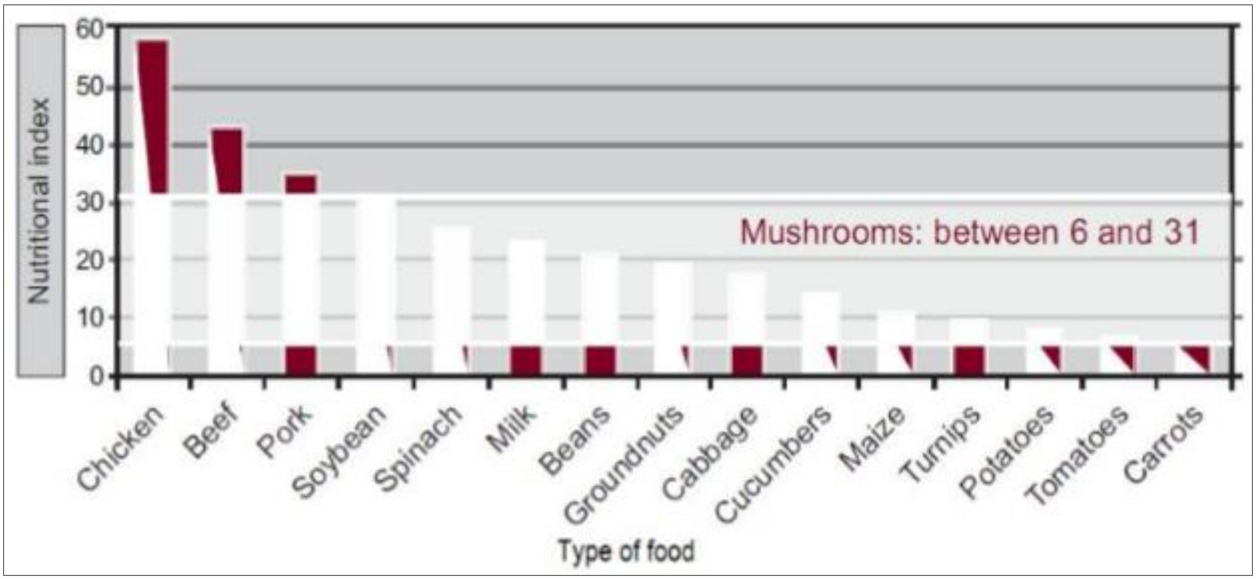

Figure 2 Comparison of mushrooms with the nutritional index of different foods (Marshall & Nair, 2009; Ferdousi *et al.*, 2020)

Mushrooms are also a great source of vitamins C and B (folate, thiamine, riboflavin, and niacin). In addition to other necessary elements (Cu, Zn, and Mg) in small amounts, minerals such as potassium, sodium, and phosphorous are found in larger concentrations in mushroom fruit bodies. However, iron and calcium are generally lacking. Enzymes, alkaloids, sterols, antioxidants, and other unidentified chemical compounds are among the substances that are most important for encouraging growth in mushrooms [144].

4.6. Medicinal Benefits of Mushrooms

Edible fungus has long been valued for their enormous health advantages and frequently utilized in folk medicine. Particular bioactive substances found in medicinal mushrooms, such as polysaccharides, triterpenoids, low-molecular-weight proteins, glycoproteins, and immune-modulating substances, have therapeutic effects [144]. Therefore, it has been demonstrated that mushrooms can strengthen the immune system, improve general health, reduce the risk of cancer, stop the growth of tumors, assist in maintaining blood sugar balance, fight off bacteria, fungi, and viruses, lessen inflammation, and support the body's detoxification processes. Due to its low-fat level, higher proportion of unsaturated fatty acids, and lack of cholesterol, the mushroom diet is excellent for the heart. It has been discovered that mushrooms, which have low sodium and high potassium content, improve human blood circulation and salt balance. They are also beneficial for people with high blood pressure [144].

Due to their low-calorie content, lack of starch, and low sugar content, mushrooms are a preferred diet for diabetic and obese people. As fiber acts as food for helpful microorganisms in the human digestive system, the fermentable dietary fiber in mushrooms enhances the normal operation of the bowel system. Kresin is one of the most often used cancer drugs in the pharmaceutical industry. It is a compound that limits tumor activity. A particular antioxidant, ergothioneine that present in *Flammulina velutipes* and *Agaricus bisporus*, is essential for the health of the eyes, kidneys, bone marrow, liver, and skin, slowing the aging process. The antioxidants found in mushrooms scavenge the body's free radicals and delay cell maturation. Thus, it functions as an anti-aging agent [144]. The human immune system is controlled and strengthened by a variety of polysaccharides (betaglucans) and minerals that were identified from mushrooms [144].

The therapeutic value of mushrooms is widely acknowledged. Health tonics, tinctures, teas, soups, and herbal formulas can all contain the 6% of edible mushrooms that have been shown to offer medical benefits [88] [200]. Due to their therapeutic benefits, edible mushrooms have been a key ingredient in the creation of some pharmaceutical products [55] [88] [111] [201]. Shiitake (*Lentinula edodes*) and Reishi (*Ganoderma lucidum*) mushrooms are well known for their medical benefits and are thought to have anti-tumor, antiviral qualities including anti-HIV and anti-hepatitis B, and the ability to eliminate serum cholesterol from the blood stream [88] [200] [328].

In Asian locations, they have been used for promoting and sustaining good health as well as the treatment of ailments since ancient times, although in the West, this strategy is much more recent. According to reports, medicinal mushrooms (MMs) have a wide range of pharmacological effects, including prebiotic, antibacterial, anti-inflammatory, immunomodulatory, antidiabetic, cytotoxic, and antioxidant qualities. They also have hepatoprotective, anticancer, antiallergic, and antihyperlipidemic capabilities [84] [105] [288] [135] [314]. Many bioactive metabolites found in the mycelium, but especially in the fruiting body, are responsible for these activities. Their biological effects vary depending on their chemical makeup, and their distribution changes depending on the type of fungus. Due to the increased interest in using natural products, including as adjuvants in conventional therapies, a great lot of research has been done and is being done to identify and characterize mycochemicals as well as to define their actions and mechanisms [84] [94] [135] [315].

The mushroom of immortality' is the Reishi mushroom [88] [146]. Natural compounds found in mushrooms have been shown to be particularly beneficial in regulating blood pressure, decreasing blood cholesterol and blood sugar levels, preserving the liver, controlling some types of cancer, increasing the immune system, and therefore promoting overall fitness [16] [88] [130].

There are a wide variety of fungal compounds that have bioactivity and may be effective in the treatment and prevention of different diseases. The most crucial are polysaccharides, which serve as building blocks for the fungal cell wall. The polysaccharides are highly effective at transporting biological information. They exhibit anticancer, immunomodulatory, antioxidant, anti-inflammatory, antibacterial, and anti-diabetic activities, to be more precise. In truth, some molecular structural characteristics, such as the weighted degree of branching, backbone linkage, side-chain units, and the kind of constituent monosaccharides, have an impact on the type and modulation of these biological activities. The most prevalent and well-known are α- and β-glucans. The biological activity is also influenced by heteroglycans, peptidoglycans, and polysaccharide-protein complexes [81] [252] [315] [357]. They have the ability to bind to particular cell wall receptors and induce particular immunological responses, which makes them principally responsible for immunomodulatory effects. Medicinal mushrooms are frequently utilized in cancer treatments as biological response modifiers (BRMs), which are beneficial for curing cancer, minimizing its side effects, and enhancing the patient's quality of life [84] [315] [329].

Table 5 Biological sources and common activities of some mushrooms

Author(s)	**Biological Source**	**Activities**
(Ajith & Janardhanan, 2003); (Lakhanpal & Rana, 2005); (Wu *et al.*, 2007); (Loganathan *et al.*, 2009); (Ganeshpurkar *et al.*, 2010); (Moro *et al.*, 2012); (Ndungutse *et al.*, 2015); (Kumar *et al.*, 2021)	*Agaricus bisporus*	-Effective scavenger of ABTS + -Antibiotic -Lower estrogen levels in the human body, reduce breast cancer susceptibility -Enhances natural killer cell activity -Anti-inflammatory -Enhance insulin secretion -Anti-ageing property
(Morigiwa et al., 1986); (Tasaka et al., 1988); (Su *et al.*, 1999); (Jones & Janardhanan, 2000); (Schlegel *et al.*, 2000); (Komoda *et al.*, 2004); (Lakshmi *et al.*, 2004); (Lin, 2004); (Ganeshpurkar *et al.*, 2010); (Xu *et al.*, 2010); (Walton, 2014); (Kumar *et al.*, 2021)	*Ganoderma lucidum*	-Effective scavenger of O_2^- and OH radicals -Hypoglycemic activity -Antifungal -Cholesterol synthesis inhibitors -Txa-2 inhibitor -Antiallergic -Angiotensin -Converting enzyme inhibitors -Antioxidant and free radical scavenging activity -Anti-metastatic -Anti-tumor -Anti-viral -Anti-HIV -Immunomodulatory -Antibiotic properties

		-Liver protection -Prevents cholesterol synthesis
(Kawagishi *et al*., 1989); (Okazaki *et al*., 1995); (Jose & Janardhanan, 2000); (Ganeshpurkar *et al*., 2010); (Menaga *et al*., 2012); (Ganeshpukar *et al*., 2015); (Kumar *et al*., 2021)	*Pleurotus florida*	-OH, radical scavenging and lipid peroxidation inhibiting activities -Radical scavenger -Antioxidant -Anti-microbial
(Ajith & Janardhanan, 2002); (Ajith & Janardhanan, 2006); (Ganeshpurkar *et al*., 2010)	*Phellinus rimosus*	-Effective scavenger of O_2^- and OH -Cytotoxic and antitumor activities
(Chye *et al*., 2008); (Ganeshpurkar *et al*., 2010)	*Hygrocybe* spp.	-Chelating effect, iron, and calcium contents
(Chye *et al*., 2008); (Ganeshpurkar *et al*., 2010)	*Hygrophorus* spp.	-Iron and calcium contents
(Sasaki & Takasuka, 1976); (de Lima Alves *et al*., 2001); (Ngai & Ng, 2003); (Sugui *et al*., 2003); (Israilidies *et al*., 2008); (Ganeshpurkar *et al*., 2010); (Attarat & Phermthai, 2015); (Chowdhury *et al*., 2015); (Kumar *et al*., 2021)	*Lentinula edodes*	-Antimutagenic effects -Immunomodulatory -Anti-tumor -Anti-inflammatory -Anti-fungal -Antioxidant -Anti-bacterial -Antifungal -Antioxidant -Hypolipidemic activity
(Barros *et al*., 2008); (Ganeshpurkar *et al*., 2010)	*Leucopaxillus giganteus*	-Effective scavenger of O_2^- -Antibiotic
(Kim *et al*., 2003); (Wang & Ng, 2006); (Lee *et al*., 2008); (Ganeshpurkar *et al*., 2010)	*Phellinus linteus*	-Potent protein glycation inhibitor -Potential antitumor agent in breast and bladder cancers -Antiarthritic activity
(Peuzuto, 1997); (Wangun *et al*., 2004); (Ganeshpurkar *et al*., 2010)	*Piptoporus betulinus*	-Antibiotic -Anti-inflammatory and antihyaluronate lyase activities
(Miguel *et al*., 1997); (Bobek & Galbavý, 1999); (Wang *et al*., 2000); (Grube *et al*., 2001); (Chu *et al*., 2005); (Khatun *et al*., 2007); (Chye *et al*., 2008); (Tong *et al*., 2009); (El-Fakharany *et al*., 2010); (Ganeshpurkar *et al*., 2010); (El Enshasy *et al*., 2012); (Oloke & Adebayo, 2015); (Kumar *et al*., 2021)	*Pleurotus ostreatus*	-Cytotoxic, apoptotic -Antihepatoma and anti-sarcoma activity -Radical scavenger -Lowers cholesterol levels - Antibacterial activities -Immunomodulatory -Hyperglycemia -Anti-tumor -Antioxidant -Anti-viral -Anti-fungal
(Lam *et al*., 2001); (Ganeshpurkar *et al*., 2010)	*Agaricus blazei*	-Antitumor activity

(Ma *et al*., 1991); (Ganeshpurkar *et al*., 2010)	*Calvatia caelata*	-Antiproliferative and antimitogenic activities
(Mizuno *et al*., 1999); (Ganeshpurkar *et al*., 2010)	*Hohenbuehelia serotina*	-Antitumor activity
(Tzianabos, 2000); (Ganeshpurkar *et al*., 2010)	*Inonotus obliquus*	-Antitumor and hypoglycemic activities
(Konno *et al*., 2002); (Lakhanpal & Rana, 2005); (Ganeshpurkar *et al*., 2010); (Kumar *et al*., 2021)	*Grifola frondosa*	-Anticancer and hypoglycemic effects -Decrease blood glucose improves insulin secretion and ovulation
(Ohno *et al*., 2002); (Ohno *et al*., 2003); (Ganeshpurkar *et al*., 2010)	*Sparassis crispa*	-Antitumor and hematopoietic activity -Immunomodulating activity
(Lam & Ng, 2001); (Akihisa *et al*., 2005); (Ganeshpurkar *et al*., 2010)	*Hypsizigus marmoreus*	-Antifungal and antiproliferative activities -Antitubercular activity
(Mlinarič *et al*., 2004); (Ganeshpurkar *et al*., 2010)	*Lactarius vellereus*	-Antigenotoxic activity
(Zhang *et al*., 2002); (Ganeshpurkar *et al*., 2010)	*Grifola frondosa*	-Cyclooxygenase inhibitor
(Faccin et al., 2007); (Ganeshpurkar *et al*., 2010)	*Agaricus brasiliensis*	- Antiviral activity
(Collins & Ng, 1997); (Ganeshpurkar *et al*., 2010)	*Coriolus versicolor*	-Anti HIV
(Lakhanpal & Rana, 2005); (Mori *et al*., 2009); (Ganeshpurkar *et al*., 2010); (Kumar *et al*., 2021)	*Hericium erinaceus*	-Cognition improvement properties -Neuritogenic effects
(Lakhanpal & Rana, 2005); (Zhang *et al*., 2007); (Kumar *et al*., 2021)	*Auricularia auricular*	-Immunomodulatory -Anti-tumor -Anti-inflammatory -Lowers cholesterol and triglycerides -Hypoglycemic activity -Immune tonic and beneficial in coronary heart disease
(Lakhanpal & Rana, 2005); (Chang et al., 2003); (Chang et al., 2010); (Wu *et al*., 2010); (Yin et al., 2010); (Kumar *et al*., 2021)	*Flammulina velutipes*	-Anti-inflammatory -Antiviral -Anti-tumor -Antioxidant activity -Immuno-modulatory -Anti-ageing property
(Lakhanpal & Rana, 2005); (Kumar *et al*., 2021)	*Cordyceps sinensis*	-Treat lung infection -Hypo-glycemic activity -Cellular health properties -Antidepressant activity
(Smiderle *et al*., 2008); (Lavi *et al*., 2012); (Kumar *et al*., 2021)	*Pleurotus pulmonarius*	-Anti-inflammatory
(Hsu *et al*., 1997); (Kumar *et al*., 2021)	*Volvariella volvacea*	-Immuno-modulatory

	
Agaricus bisporus (Ultimate Mushroom, 2021)	*Lentinula edodes* (Mycelia, 2023)
	
Pleurotus spp. (Mushroom Mountain, 2023)	*Ganoderma sichuanense* (TEC, 2023)
	
Hypsizygus tessellatus (Hive Blog, 2020)	*Grifola frondose* (Fungi Natur, 2022)
	
Cantharellus cibarius (UAB Njordas, 2023)	*Boletus edulis (Forest Floor Narrative, 2019)*

	
*Schizophyllum commune (*Forest Floor Narrative, 2017)	*Phellinus spp.* (Ultimate Mushroom, 2021)
	
Agaricus Blazei (Healing Mushrooms, 2023)	*Antrodia cinnamomea* (Indigo Herbs, 2023)
	
Coriolus versicolor (Science Direct, 2019)	*Hericium erinaceus* (Endeavour, 2023)

Figure 3 Medicinal Mushrooms

The terpenes, which are made up of units of five-carbon isoprene atoms and are particularly significant for their bioactivity, are a different family of chemicals. By adding functional groups, terpenes create terpenoids. Besides having anti-inflammatory, antioxidant, and anticancer activities, they affect the immune system by promoting the expression of genes that code for immune response-related proteins. Species of mushrooms in the genus *Ganoderma* P. Karst have high terpenoid concentrations [81] [84] [315] [357]. Proteins in mushrooms are abundant and have cytotoxic and anticancer activities. Some of them are well-known for having a distinctive and noticeable immunomodulatory action. These proteins are identified as fungal immunomodulatory proteins (FIPs) with a variety of potential modes of action [84] [315] [357].

Additionally, proteins have lectins, which have a high selectivity reversible binding to mono and oligosaccharides, detecting and interacting with different carbohydrates and proteoglycans on the cell surface. Their immunomodulatory mechanism varies depending on the origin of the chemical, and they are engaged in a wide range of biological processes, including innate immunity and cell-to-cell communication. Additionally, they have anticancer, antiproliferative, and immunomodulatory qualities [81] [315] [357]. Other fungal byproducts that have biological function include phenolic compounds, antioxidants with various modes of action (oxygen scavenging, metal inactivation, free radical suppression, and peroxidase breakdown), laccases (copper-containing oxidases), and fatty acids [84] [315].

4.7. Economic Benefits of Mushrooms

Due to their great nutritional value for humans and their therapeutic qualities, mushrooms can aid in the treatment of diseases and malnutrition. In addition to being a significant food item, man also uses mushrooms in a variety of ways. Additionally, they are advantageous to the forest [144].

One of the most potential resources for accelerating socioeconomic development is mushrooms [88] [201]. Mushroom farming generates revenue for the nation and helps to reduce poverty. The production of mushrooms generates a significant amount of direct and indirect employment prospects in the fields of cultivation and marketing, as well as providing opportunities for processing businesses and labor-intensive management [88] [130] [200]. Mushroom farming requires minimal capital, little technical expertise, and it is even possible to grow mushrooms indoors on a modest scale and quickly earn a good return on investment. Women can grow mushrooms in their homes similarly to raising chickens with little capital [79] [88] [130] [268]. As a result, mushroom farming not only gives rural women more power but also fights poverty at its source.

In Bangladesh, due to their high market price, mushrooms are a much more lucrative agricultural product than vegetables. According to a study on the economics of mushrooms, the average gross margin was BDT 38790, the average net return was BDT 22888, and the average BCR was 1.55. Oyster mushroom cultivation on several types of sawdust revealed high BCR values, which varied from 3.6 to 4.25 [88] [209]. Easin *et al*. (2017) reported a high BCR (2.24) for mushroom growing as a modest family business. When rice, wheat, and mushroom agriculture were compared in terms of profitability, it became clear that mushroom production was the most profitable [88] [123].

Table 6 Checklist of some medicinal mushrooms

Author(s)	Mushroom Species	Scientific Name	Description of Uses and Bioactive Compounds (Effects and Mechanisms of In Vitro and In Vivo Preclinical Studies)
(Taguchi *et al.*, 1985); (Taguchi *et al.*, 1985); (Mizuno, 1999); (Wang & Ng, 2000); (Wang & Ng, 2001); (Smith *et al.*, 2002); (Ngai & Ng, 2003); (Wang & Ng, 2003); (Chen, 2006); (Wu *et al.*, 2007); (Adams *et al.*, 2008); (Loganathan *et al.*, 2009); (Ganeshpurkar *et al.*, 2010); (Atila *et al.*, 2017); (Muszynska *et al.*, 2018); (Ahmed *et al.*, 2020); (Blumfield *et al.*, 2020); (Kakraliya, 2020); (Venturella *et al.*, 2021)	White Mushroom, Button Mushroom or Table Mushroom	*Agaricus bisporus*	*Agaricus bisporus* (Figure 3) is a cultivated edible basidiomycete that is often known as the button mushroom or table mushroom and is widely distributed throughout Europe and North America. It is conceivably among the mushroom species that is most widely cultivated worldwide. Due to the presence of certain antioxidants, *A. bisporus* extract, both boiled and raw, successfully suppressed the oxidative crisis in in vitro experiments. Selenium, which helps with weight loss and is believed to prevent prostate cancer, is found in white mushrooms. These mushrooms contain a unique type of carbohydrate that boosts metabolism and keeps blood sugar levels stable. Beta-glucans, ergosterol, ergothioneine, vitamin D, and flavonoids are all present in different amounts in *Agaricus bisporus*, depending on the length and type of cooking as well as UVB exposure. In addition, this mushroom is significant for its potential use as an antimicrobial, anticancer, antidiabetic, antihypercholesterolemic, antihypertensive, hepatoprotective, and antioxidant agent. It also contains essential amino acids, peptides, glycoproteins, nucleosides, glycoproteins, triterpenoids, lectins, fatty acids, and their derivatives. Due to the activity of conjugated linoleic acid (CLA), it is advised to include *A. bisporus* in the diet to prevent prostate cancer. In particular, CLA prevents prostate cancer cell lines from proliferating in living organisms. By preventing the development of prostate cancer in athymic mice, the therapy demonstrated an antiproliferative and proapoptotic action of mushroom extracts. After adding 0.75% (v/v) ethylene glycol to drinking water for nine weeks, hyperoxaluria-induced urolithiasis in Wistar rats was established. The nephroprotective effects of *P. ostreatus* and *A. bisporus* aqueous extracts on this condition were studied. The mushroom extracts had nephroprotective properties against renal failure brought on by ethylene glycol and slowed the progression of nephrolithiasis. In vitro *A. bisporus* biomass extracts' anti-inflammatory and antioxidant capabilities were highlighted by Muszynska *et al.* When compared to cells that had been stimulated by LPS- and/or TNF-α, Caco-2 cells treated with *A. bisporus* extracts showed a lower expression of cyclooxygenase-2 and prostaglandin F2α receptor. The polysaccharide fraction of *A. bisporus* extract, which is commercially marketed as a dietary supplement for use as an immune stimulant and kidney tonic, is also proposed as an anticancer substance due to its immune stimulating effects. One of the key dietary components that can lessen a woman's risk of developing hormone-dependent breast cancer is the button mushroom. Considering that they are widely accepted by people, easily accessible, economical, and available, they may therefore be a good preventative method.

			Due to its limited range of activity, *A. bisporus* is also efficient against *Bacillus subtilis* in addition to having potential activity against gram positive and, to a lesser extent, gram negative bacteria. It is known that some antifungal proteins, lectins, ribonucleases, and laccases from mushrooms can suppress HIV 1 reverse transcriptase.
(Chihara *et al*., 1970); (Akoi, 1984); (Taguchi *et al*., 1985); (Suga *et al*., 1986); (Taguchi *et al*., 1985); (Maeda *et al*., 1991); (Chihara, 1992); (Bohn & BeMiller, 1996); (Kurashiga *et al*., 1997); (Wasser & Weis, 1999); (Smith *et al*., 2002); (Bender *et al*., 2003); (Ganeshpurkar *et al*., 2010); (Finimundy *et al*., 2013); (Ina *et al*., 2013); (Li & Zhang, 2014); (Ahn *et al*., 2017); (Deng *et al*., 2018); (Zhang *et al*., 2018); (Kakraliya, 2020)	Shiitake Mushroom	*Lentinula edodes* (formerly *Lentinus edodes*)	Another substance authorized for usage in Japan is lentinan, a 1,3-D-glucan derived from the shiitake mushroom *Lentinula edodes* (Figure 3). Due to its immunomodulatory activity, lentinan is used extensively in Japan to treat malignancies, particularly stomach cancer. The Th1/Th2 equilibrium can be enhanced and the Th1 response can be promoted by the BRM lentinan. The polysaccharide activates dendritic cell function by increasing levels of tumor-infiltrating CD86+ cells, stimulating the production of T and NK cells, reestablishing the killer/survival cell ratio, enhancing FcR receptor expression and thus promoting NK cell-mediated tumor cell killing, and raising levels of IL-2. These effects have been observed in numerous in vitro studies as well as in vivo mouse models. The metabolite also seems to increase complement-dependent cytotoxicity (CDC) and complement-dependent cell-mediated cytotoxicity through the CR3 receptor, which is known to be activated by iC3b in fungal cell walls. By binding to pattern recognition receptors including TLR2/4/6/9 and Dectin-1, the complement receptor CD11b, and other membrane receptors, it is able to activate downstream signaling pathways such as MAPK-NFB and SykPKC, which in turn activates T cells, NK cells, and macrophages. Furthermore, it has been demonstrated in both in vitro and in vivo studies to increase the cytotoxic activity of primary macrophages and RAW264.7 cell lines, as well as cytotoxicity and TNF secretion in macrophages, and cytotoxicity against sarcoma S180 cells by upregulating the proapoptotic protein Bax and downregulating the antiapoptotic protein Bc1-2, thereby inducing apoptosis. According to a study conducted in vitro using C6 rat glioma cells, the activity of lentinan is also expressed via interfering with cell cycles. The induction of apoptosis, cell cycle blockage, a rise in the proportion of cells in G0/G1 phase, and a decrease in the number of cells in S-phase were all seen as a result of the substantial dose- and time-dependent inhibition of the C6 cells' activity. The innate immune system's inflammasomes, which are responsible for inducing inflammatory responses, can also be affected by lentinan. The findings of a study by Ahn *et al*. on myeloid cells, using mouse bone marrow-derived macrophages treated with lentinan with/without inflammasome triggers, suggest that this action. Lentinan was discovered to upregulate proinflammatory cytokines, preferentially suppress absent in melanoma 2 (AIM2) inflammasome activation, and promote the production of inflammasome-related genes through TLR4 signaling. In addition, the researchers discovered that lentinan reduced IL-1 secretion due to activation of the *Listeria*-mediated AIM2 inflammasome and also decreased dopamine toxicity by inhibiting the activation of the non-canonical inflammasome in mice treated with *Listeria monocytogenes* or lipopolysaccharide as an AIM2 or non-canonical inflammasome-mediated model. In a study using the colorectal cancer cell line CT26 and the lung carcinoma cell line LAP0927, lentinan was shown to have an inhibitory effect on tumor angiogenesis that was mediated by elevated IFN- production.

			In addition to increased tumor infiltration of myeloid and T cells that express IFN-y, the polysaccharide amplified the production of angiostatic factors, most notably IFN-y. There are also numerous preclinical studies that support the use of lentinan as an adjuvant in oncological therapies. These studies evaluated the polysaccharide with drugs used in chemotherapy. For instance, it has been demonstrated that lentinan activates the Nrf2-ARE signaling pathway to reduce the ROS-mediated nephrotoxicity of cisplatin, a major medication in the treatment of lung cancer. Similar to this, activating the ASK1/p38 MAPK signaling pathway and, consequently, the thioredoxin-interacting protein (TXNIP)-associated NLRP3 inflammasome (TXNIP-NLRP3), caused the tumor medication paclitaxel to have a synergistic effect on A549 cells. Shiitake's aqueous extract, particularly rich in polyphenols, was evaluated on human tumor cell lines of cervical adenocarcinoma (HeLa) and laryngeal carcinoma (Hep-2) to determine its antiproliferative activity. The *Pleurotus sajor-caju* (Fr.) Singer extract, which was also evaluated in this study, although to a lesser extent, shown high levels of free radical scavenging, catalase-like, and cytotoxic activities, as well as the suppression of cell growth and the induction of apoptosis. *L. edodes* is the source of lentinan and *L. edodes* mycelium [LEM] extract, both of which have potent pharmacological effects. Lentinan works by triggering a variety of immunological responses in the host to produce its anticancer effect. The development, differentiation, or proliferation of cells involved in host defense systems is what causes this immunomodulation. Lentinan thereby boosts the host's resistance to many cancers and has the potential to help patients' immune systems recover. The same amounts of lentinan that are seen in the blood plasma of patients receiving therapeutic lentinan treatment can be used to activate NK cells in vitro. Tumor suppression is a function of NK cell activity, and while these cells do not boost all T killer cell activity—or do so only under specific circumstances—they are potent stimulators of T helper cells both in vitro and in vivo. Lentinan is also reported to increase in the activation of non-specific inflammatory response, such as acute phase protein production. It also enhances vascular dilation and hemorrhage inducing factor in vivo. Lentinan can inhibit prostaglandin synthesis, which can slow T cell differentiation in animals and humans, as well as inhibiting suppressor T cell activity. When compared to other mushroom polysaccharides, lentinan is the only isolated chemical that has demonstrated stronger anticancer and antiproliferative properties. Numerous xenografts that contained pure mushroom polysaccharides demonstrated tumor remission. Lentinan's cytostatic action is primarily brought about by the stimulation of the host immune system. The glycoprotein lentinan has also demonstrated anticancer action in xenograft models. Lentinan is a pure polysaccharide made exclusively of carbon, oxygen, and hydrogen atoms. Lentinan, thus, has demonstrated success in extending cancer patients' overall survival, particularly in individuals with gastric and colorectal cancer. Oxalic acid, which is present in *Lentinula edodes* and has an antibacterial impact on *Staphylococcus aureus* and other microorganisms. Additionally, *Lentinula edodes* mycelium ethanolic extract has antiprotozoal action against *Paramecium caudatum*.

			Due to their high concentration of lentinan, a naturally occurring anticancer chemical, shiitake mushrooms have the ability to combat cancers. These succulent, meaty mushrooms are a great source of vitamin D and help prevent infections.
(Devita *et al*., 1993); (Gunde-Cimmerman, 1999); (Gune-Cimmerman *et al*., 1993); (Chang, 1999); (Jose & Janardhanan, 2000); (Jose *et al*., 2002); (Smith *et al*., 2002); (Sarangi *et al*., 2006); (Jedinak & Silva, 2008); (Ganeshpurkar *et al*., 2010); (Jedinak *et al*., 2011); (Popovic´ *et al*., 2013); (Sun *et al*., 2017); (Kakraliya, 2020); (Venturella *et al*., 2021)	Oyster Mushroom	*Pleurotus spp.*	The edible oyster mushroom (*Pleurotus* spp.) (Figure 3) is a popularly cultivated mushroom. Even though they are not the most well-known therapeutic mushrooms, the *Pleurotus* species have established biological benefits. Numerous studies have been conducted to evaluate their antioxidative, antimicrobial, antidiabetic, anticancer, anti-inflammatory, immunomodulatory, anti-hypercholesterolemic, anti-hypertensive, antimicrobial, hepatoprotective, and antiaging properties; however, the mechanisms underlying these effects have frequently not been clarified, nor have the responsible metabolites been identified or characterized. By evaluating, in vitro and in vivo, the impact of water-soluble proteoglycan fractions isolated from *Pleurotus ostreatus*, or oyster mushroom, on a sarcoma-180 bearing mice model, Sarangi *et al*. revealed the immunomodulatory and anticancer effects of *Pleurotus ostreatus* (Jacq.) P. Kumm. Treatment with the mushroom caused a quantitative decrease in tumor cells and their arrest in the pre-G0/G1 phase of the cell cycle, as well as an increase in the cytotoxicity of NK cells and the induction of nitric oxide production in macrophages. *P. ostreatus* (PO) emerged as the most efficient medical mushroom in a study by Jedinak and Sliva (2008) examining the effects of various medicinal mushrooms on the growth of breast and colon cancer cells, reducing cell proliferation via the p53-dependent and p53-independent pathways. More specifically, the methanolic extract of the mushroom caused cell cycle arrest in the G0/G1 phase in MCF-7 and HT-29 cells and induced the inhibition of the proliferation of the human breast cancer cell lines MDA-MB-231 andMCF-7 and colon cancer cell lines HCT-116 and HT-29. Additionally, it increased the expression of the tumor suppressor p53 and the cyclin-dependent kinase inhibitor p21 (Cip1/Waf1) in MCF-7 cells and reduced the phosphorylation of the retinoblastoma protein Rb. These effects were also shown in HT-29 cells. Later on, Jedinak *et al*. (2008) tested a mushroom concentrate on RAW264.7 murine macrophage cell line and murine splenocytes in vitro, in the presence or absence of lipopolysaccharide (LPS) or concanavalin A (ConA), and in vivo on Balb/c mice with LPS-induced inflammation. PO suppressed the LPS-induced secretion of TNF-α, IL-6, and IL-12 from macrophages and inhibited the LPS-induced production of prostaglandin E2 (PGE2) and nitric oxide (NO) through, respectively, the downregulation of the expression of COX-2 and iNOS, the suppression of the LPS-dependent activation of AP-1 and NF-κB, the suppression of the secretion of TNF-α and IL-6 in mice challenged with LPS in vivo, and the inhibition of ConA-induced splenocyte proliferation and the production of IFN-γ, IL-2, and IL-6. In breast, cervical, and stomach cancer cells, a polypeptide (PEMP) isolated from *Pleurotus eryngii* (DC.) Quél. mycelium showed considerable free radical scavenging and anticancer activity, as well as an activating influence on the macrophage-mediated immune response. It reduced tumor cell growth in a dose-dependent manner, boosted macrophage growth, the expression of TNF- and IL-6 production, TLR2 and TLR4, and macrophage phagocytosis through the emission of NO and H_2O_2. On human HCT116 colon cancer cell lines, cold-waterextracts of *P. eryngii* var. *ferulae*

			(Lanzi) Sacc. and *P. nebrodensis* (Inzenga) Quél. demonstrated significant in vitro anticancer activity. Both therapies significantly increased the Bax/Bcl2 mRNA ratio, markedly reduced the ability of cancer cells to survive, and induced apoptosis. They also inhibited cell migration, altered homotypic and heterotypic cell-cell adhesion by increasing the expression of E-cadherin, and negatively regulated the phosphorylation of both protein tyrosine and extracellular signal-regulated kinase ERK1/2. By blocking the autocrine vascular endothelial growth factor (VEGF)-induced PI3K/AKT signaling cascade, a hot-water extract of *Pleurotus pulmonarius* (Fr.) Quél. has been found to decrease liver cancer cell proliferation and invasion in vitro and in vivo. It has been discovered that some *Pleurotus* species possess anti-inflammatory, anti-tumor, and antioxidant chemicals. It is discovered that *P. florida*'s fruiting body contains methanolic extract lipid peroxidation inhibition and OH radical scavenging capability. These are highly medicinal. The substances that were extracted from them have antihypertensive and antihypercholestremic properties. The Ehrlich's ascites carcinoma (EAC) cell-line induced solid tumor model in mice was successfully treated with a methanolic extract of *Pleurotus florida* fruiting bodies from South India. The nutrients in oyster mushrooms are abundant. Zinc, iron, potassium, calcium, phosphorus, vitamin C, folic acid, niacin, and vitamins B-1 and B-2 are all present in large amounts. It has a high concentration of antioxidant components, is known to protect us from a number of ailments, and also aids in reducing stress.
(Zhao & Zhang, 1994); (Liu, 1999); (Mau *et al*., 2002); (Smith *et al*., 2002); (Miyamoto *et al*., 2009); (Ganeshpurkar *et al*., 2010); (Lee *et al*., 2010); (Trigos & Medellín, 2011); (Popovic´ *et al*., 2013); (Kim *et al*., 2016); (Xie *et al*., 2016); (Thawthong *et al*., 2017); (Bulam *et al*., 2019); (Kakraliya, 2020); (Xu et al., 2020)	Reishi Mushroom or Mushroom of Immortality	*Ganoderma sichuanense*	*Ganoderma sichuanense* (Figure 3) is a medicinal mushroom originally described from China and previously confused with *G. lucidum*. The longest-running historical use of *Ganoderma sichuanense* and several related species is described. Due to their medical benefits, *Ganoderma* spp. became a well-known tonic and held a significant position in Chinese medicine around 4000 years ago. This is because to their favorable effects on all viscera and nontoxic nature. *Ganoderma sichuanense*, commonly known as ling zhi or reishi, has long been referred to as the "mushroom of immortality" and is one of the most popular medicinal mushrooms in use today. Since it was listed in Shen Nong's Materia Medica (206 BC–8 AD), the American Herbal Pharmacopoeia, Chinese Pharmacopoeia, and Therapeutic Compendium, it has been used to promote health and longevity in traditional Chinese medicine. It is also frequently used as an adjuvant in the treatment of various types of cancer. There are currently more than 100 reishi-based products on the market, including the nutraceuticals Immunlink MBG and Ganopoly, which contain aqueous polysaccharide fractions, as well as a variety of supplements, functional foods, mycopharmaceuticals, and cosmeceuticals made from carpophores, mycelia, or spore powder. Anticancer, hypoglycemic, immunomodulatory, antihypertensive, cytotoxic, anti-diabetic, antioxidant, antihyperlipidemic, antimutagenic, anti-aging, antimicrobial, and hepatoprotective qualities are just a few of the many pharmacological traits that *G. sichuanense* is known for. Triterpenes/triterpenoids and polysaccharides, two primary categories of metabolites found in *G. sichuanense*, are primarily responsible for these characteristics. Triterpene compounds, which

			include lucidones, lucinedic acids, ganoderic acids, ganodermic acids, and ganodermic alcohols, are derivatives of lanosterol and have strong anticancer, antimetastatic, cytotoxic, and enzyme inhibitory effects. The main polysaccharides include α-1,3, β-1,3 and β-1,6-D-glucans and ganoderan, which have powerful antiangiogenic and immune system-boosting characteristics. Glucose is the main sugar component. In addition to its immunomodulating, immune stimulating, antioxidant, and anti-inflammatory capabilities, these two groups of chemicals are principally accountable for the anticancer properties of fucoidan, reducing cell proliferation, metastasis, and invasion as well as encouraging apoptosis. The activation of cytotoxic T cells, B lymphocytes, dendritic cells, macrophages, NK cells, the TLR-4 pathway, and other immune cells, as well as the production of TNF-α, interleukins IL-1, IL-2, IL-3, and IL-6, as well as active nitrogen and oxygen intermediates, are just a few examples of the various mechanisms by which immunomodulatory action is observed to occur. According to research by Lee *et al*., the *G. sichuanense* triterpenes butyl ganoderate A and B and butyl lucidenate A and N inhibit adipogenesis in 3T3-L1 cells. The first and final of these substances carried out this function by reducing the mRNA expression levels of the genes for acetyl-CoA carboxylase (ACC) and fatty acid synthase (FAS). The researchers came to the conclusion that the downregulation of the adipogenic transcription factor sterol regulatory element-binding protein 1 (SREBP-1c) and its targets Fanconi anemia (FA) group C gene (FAC) and ACC is at least partially responsible for the inhibitory activity of these triterpenes on 3T3-L1 cells. In vitro tests on Lewis lung carcinoma, sarcoma 180, T-47D, and Meth-A tumor cell lines demonstrated the cytotoxic action of lucialdheydes A and C, ganodermanonol, and ganodermanondiol. An in vivo experiment using mice injected with inflammatory breast cancer (IBC) and treated with the commercial extract ReishiMax GLpTM (carpophore and cracked spores) revealed a selective action on gene and protein expression, resulting in smaller tumor size and weight and decreased expression of E-cadherin, mammalian target of rapamycin (mTOR), human eukaryotic translation initiation factor 4G (eIF4G), and p70 ribosomal protein S6 kinase (p70S6K) and the activity of extracellular regulated kinase (ERK 1/2). Reishi terpenes, polysaccharides, and proteins have been shown to have an antiproliferative and proapoptotic effect in vitro by promoting the growth of undifferentiated spleen cells and the production of cytokines and antibodies. Additionally, they have an antimetastatic effect that they carry out via triggering the NF-B and MAP kinase pathways and triggering cytokine release. The effects of ganoderic acids have been studied extensively; for example, it has been demonstrated that ganoderic acid T induces apoptosis in metastatic lung cancer cells by acting on the pathway associated with mitochondrial malfunction and the production of the tumor protein p53. Ganoderic acid D also caused G2/M cell cycle arrest and death in HeLa human cancer cells and reduced their ability to proliferate. By inhibiting the expression of c-Fos and nuclear factor of activated T-cells c1 (NFATc1), ganoderic acid DM has been demonstrated to arrest osteoclastogenesis in bone marrow cells and RAW 264 cell D-clone (RAWD). This results in the inhibition of dendritic cell-specific transmembrane protein (DC-STAMP) expression and decreased osteoclast fusion.

			In their preliminary study, which used transverse aortic constriction (TAC) in mice to model pressure overload-induced cardiomyopathy and treatment with spore oil, they also reported cardioprotective activity. The treatment resulted in a normalized ejection fraction, corrected the fractional shortening generated by TAC, and reduced left ventricular hypertrophy; analysis of total RNA expression revealed the reduced expression of genes associated with cardiac failure, as well as reduced levels of RNA circ-Foxo3. By evaluating its inhibitory effects on tyrosinase activity and melanin manufacture in B16F10 melanoma cells, ganodermanondiol has also been reported by Kim *et al*. for its inhibitory effect on melanogenesis. The researchers noted that reduced melanin formation was caused by the reduction of cellular tyrosinase activity and expression, as well as of the expression of tyrosinase-related protein-1 (TRP-1), TRP-2, and microphthalmia-associated transcription factor (MITF). Additionally impacted were the cyclic adenosine monophosphate (cAMP)-dependent signaling pathway and the mitogen-activated protein kinase (MAPK) cascade. Reishi is an ideal choice for the creation of skincare products as a result of these findings. An H2O2-induced stem cell senescence model using human amniotic mesenchymal cells (hAMSCs) with a high expression of -galactosidase, a senescence-associated marker, was used to test the effects of ganoderic acid D on oxidative stress-induced stem cell senescence. This study demonstrated an antiaging effect of *G. sichuanense*. Through the stimulation of the PERK/NRF2 signaling pathway, ganoderic acid D increased telomerase activity while decreasing the production of reactive oxygen species (ROS) and senescence-associated markers such β-galactosidase, p21, and p16INK4a. More than 400 of the other bioactive metabolites that *G. sichuanense* contains are listed. These metabolites have a wide range of diverse effects. In addition to those already mentioned, there are peptides (such as GLP from the water-soluble extract, which may be the primary factor causing the fungus's alternative oxidase (AOX) activity), peptidoglycans (such as GLPP, which can mitigate ROS damage in rat macrophages, and ganoderan C with hypoglycemic activity), polyphenols, ergostan sterols, and ergosterol, alkaloids, fatty acids with tumor proliferation-inhibiting action, nucleotides and nucleosides with platelet aggregation effects, the α-glucosidase inhibitor SKG-3, and laccase isoenzymes with antiviral properties. Reishi mushrooms have qualities that meet all of our needs for disease defense. Anti-cancer, antioxidant, anti-bacterial, anti-viral, and anti-fungal capabilities are well documented in them. Additionally, the gandodermic acid in these mushrooms lowers bad cholesterol, which in turn lowers high blood pressure. Phenolics and other phytoconstituents in *Ganoderma* were discovered to exhibit antioxidant and chelating activity in addition to reducing power and chelating abilities after effectively scavenging the O_2; OH, radical produced experimentally during in vitro tests. In the past, 2000 years ago, China and other Asian nations have made considerable use of *Ganoderma sichuanense.* From this fungus, substances with powerful immunomodulating properties have been extracted, including polysaccharides [particularly -D-glucan], proteins [such as Ling Zhi 8], and triterpenoids. Mice and chicken macrophages can be strongly stimulated by a protein-polysaccharide fraction [GLB] and a -D-glucan [Ganoderan] from *G. sichuanense*. On these

			antigen-presenting macrophages, ganoderan and GLB have been demonstrated to boost the expression of MHC class II molecules. Additionally, there is proof that *G. sichuanense* extracts may affect B-cell or humoral immunity. The complement system's conventional and alternative pathways were both activated by an alkali extract from the fungus *G. sichuanense*. Additionally, this extract stimulated the reticuloendothelial system and increased the number of cells that form hemolytic plaques in mouse spleens.
(Kakraliya, 2020)	Shimeji Mushroom	*Hypsizygus tessellatus*	Tumors can be fought with *Hypsizygus tessellatus* (shimeji mushrooms) (Figure 3). By increasing the immune system and its capacity to recover, they can also aid with diabetes, asthma, and some allergies. They are rich in vitamin D and other critical elements including zinc, copper, and manganese.
(Nishida *et al*., 1988); (Smith *et al*., 2002); (Gu & Gowsala, 2006); (Alonso *et al*., 2013); (Alonso *et al*., 2017), (Alonso *et al*., 2018); (Xiao *et al*., 2015); (Chui *et al*., 2016); (Kakraliya, 2020)	Maitake Mushroom	*Grifola frondosa*	Maitake, also known as *Grifola frondosa*, (Figure 3) is another popular medicinal fungus with a wide range of therapeutic benefits. Its principal bioactive metabolite is the so-called D-fraction, also known as GFP, a -glucan proteoglycan molecule. Numerous experiments, including the one by Alonso *et al*. on MCF-7 human breast cancer cells, have proven its anticancer activity. Taking maitake mushrooms can help prevent breast cancer. This mushroom's B D Glucan and glycoprotein complexes have demonstrated potent anticancer action in xerographs. There is now a highly pure extract called β-glucan [β-1, 6 glucan branched with a β-1, 3-linkage] that is orally accessible and exhibits significant immunomodulating and anticancer effects in animal models. In addition to stimulating apoptosis, inhibiting cell growth and proliferation and cell cycle arrest, preventing tumor cell migration and metastasis, and downregulating the PI3K-AKT signaling pathway, it also activated macrophages, T cells, and NK cells in addition to activating BCL2-antagonist/killer 1 (BAK-1) and several other genes (RASSF-2, FADD, IGFBP-7, ITGA2, ICAM3, SOD2, CAV-1, Cul 3, NRF2, CyclineE, ST7, and SPARC). In a subsequent experiment, it was discovered that D-fraction increased cell adhesion by upregulating Ecadherin protein levels and inhibiting matrix metalloproteinase-2 (MMP-2) activity in rodent LM3 mammary adenocarcinoma cells, in addition to inducing apoptosis and decreasing cell motility and invasiveness. In addition to the effects just mentioned, it also repressed MMP-9 and decreased cell-cell adhesion in triple-negative breast cancer (TNBC) cells by also boosting the membrane localization of the -catenin protein. As a result of the reactivation of the insulin receptor (IR) and insulin receptor substrate-1 (IRS-1), two polysaccharide fractions obtained from GFPs and designated as F2 and F3 demonstrated promising hypoglycemic effects in vitro. Both fractions decreased fasting serum glucose (FSG), fasting serum insulin (FSI), and the homeostasis model assessment of insulin resistance (HOMA-IR), as well as increased IR and IRS-1 activities and the insulin receptor substrate (PI3K/Akt pathways, as seen from the increased mRNA levels of PI3K and Akt). However, a variety of additional biologically potent substances have been isolated from maitake and studied for their potential health benefits. This is the case, for instance, with GFG-3a, a novel glycoprotein isolated from fermented *G. frondosa* mycelium. By affecting the stress response, p53-dependent mitochondrial-mediated, caspase-8/-3-dependent, and PI3k/Akt pathways, it can

			cause apoptosis in human SGC-7901 gastric cancer cells; apoptosis, cell cycle arrest at S phase, and the modulation of the expression of 21 proteins were observed, in particular, the upregulation of 10 proteins, including RBBP4, associated with cell cycle arrest and the downregulation of 11 proteins (including RUVBL1, NPM, HSP90AB1, and GRP78, involved in apoptosis and stress response). Including mushrooms in our diet on a regular basis is proven to help us stay healthy and maintain a strong immune system.
(Kakraliya, 2020)	Chanterelle Mushroom	*Cantharellus cibarius*	Our eyes, lungs, and immune systems are all known to benefit from *Cantharellus cibarius* (chanterelle mushrooms) (Figure 3). Anti-microbial, anti-bacterial, and anti-fungal characteristics are known to exist in these mushrooms. They are also rich in potassium, vitamin D, and C.
(Smith *et al.*, 2002); (Kakraliya, 2020)	Porcini Mushroom	*Boletus edulis*	There is evidence that *Boletus edulis* (porcini mushrooms) (Figure 3) reduce inflammation. This meaty mushroom has a substance called ergosterol that has the ability to combat ailments that are caused by infections. They include a lot of fiber, which naturally keeps us from being constipated, as well as a lot of calcium, which strengthens our bones.
(Yan 1987); (Okazaki et al., 1995); (Smith *et al.*, 2002); (Ganeshpurkar *et al.*, 2010)	Split Gill Mushroom	*Schizophyllum commune*	*Schizophyllum's* (Figure 3) anticancer action is mostly a result of host-mediated immunological responses. The effects of [1-3]-d glucans on the host's immune system may: • Increase helper T-cell production; • Increase macrophage production; • Cause a nonimmunological increase in the host defender mechanisms through stimulation of acute-phase proteins and colony-stimulating factors, which in turn effects macrophage proliferation. *Schizophyllum* is a T-cell oriented immunopotentiator and as such requires a functional T-cell component for its biological activity.
(Ying et al., 1987); (Sharma, 1995); (Song *et al.*, 1995); (Dai & Xu, 1998); (Mizuno, 1999); (Ajith & Janardhanan, 2001); (Smith *et al.*, 2002); (Kim *et al.*, 2003), (Lee *et al.*, 2005); (Ajith & Janardhanan, 2002); (Ajith & Janardhanan, 2006) (Ganeshpurkar *et al.*, 2010)	Cracked Cap Polypore	*Phellinus spp.*	Tropical forests and plains are where the species is primarily found. In Chinese medicine, the fruiting bodies of *Phellinus* spp. (Figure 3) have been reported to be used to treat a variety of illnesses and are thought to rejuvenate the body and increase longevity. When examined in vitro, various extracts of *Phellinus* spp. were found to scavenge O2, OH, and nitric oxide radicals produced by free radicals. *P. linetus* is a basidiomycetes fungus that is primarily found in America, Africa, and Asia and is known for its therapeutic properties. From *P. linetus*, polysaccharides, acidic proteoheteroglycans with mixed α, β linkage, and a [1-6] - branching type [1-3]-glycan have been isolated as the biologically active components. These intricate polysaccharides have been found in a wide range of mushroom species and have been connected to immunostimulatory and anticancer properties. Downregulation of the m-RNA level of the enzyme urokinase plasminogen activator (μPA) and suppression of pulmonary metastasis in mice are used to prevent the invasion of melanoma B 16 cells.

(Mizuno, 2002), (Smith *et al.*, 2002); (Murakawa *et al.*, 2007), (Ellertsen & Hetland, 2009), (Ishibashi *et al.*, 2009), (Niu *et al.*, 2009), (Lima *et al.*, 2016), (Gargan *et al.*, 2017), (Venturella *et al.*, 2021)	Almond Mushroom	*Agaricus blazei*	Numerous bioactive substances found in *Agaricus blazei* (Figure 3) stimulate the immune system to perform a variety of protective actions. *A. blazei* is useful for treating diabetes, HIV/AIDS, hypotension, and hepatitis. Numerous animal investigations and clinical experience have shown that the fungus also has anticancer and immunological boosting activities. The primary components of *A. blazei* that stimulate the immune system and function as antitumoral against myeloma and hepatic cancer in in vivo and in vitro investigations are called β-glucans. Some in vitro and in vivo preclinical studies on the effectiveness of *A. blazei* extracts have demonstrated action against Gram-positive and Gram-negative bacteria, while more research is necessary. The *A. blazei* mushroom extract, in particular, encourages an antibacterial effect against oral infections that can be fatal as well as peritonitis. An additional investigation focuses on the clinical impact of oral *A. blazei* treatment on the antibody response to -glucan (anti-BG) titer. *A. blazei* caused a reaction that was specific to β-glucans when taken orally. The generation of anti-BG antibodies that followed could be used as a gauge of how well humans' immune systems respond to β-glucan. Antiallergic properties may result from the β-glucans of *A. blazei* impact on the immune system. Such actions have been demonstrated in vivo and in animal studies to have an effect on the immune system's balance of Th1/Th2 cells.
(Chen *et al.*, 2019); (Kumar *et al.*, 2019); (Venturella *et al.*, 2021)	Niu-Chang-Chih	*Antrodia cinnamomea*	Anctin-A (ATA) is a bioactive steroid-like compound that was isolated from *Antrodia cinnamomea* (Figure 3), also known as the AC mushroom. Although not well-known in the West, this endemic species of mushroom is widely used in Taiwan to treat liver disorders brought on by excessive alcohol consumption. In addition to its hepatoprotective properties, it also has many other recognized therapeutic properties. This mycochemical was found to inhibit tumor growth in human MCF-7 and MDA-MB-231 breast cancer cells. It did this by upregulating E-cadherin and occludin proteins, downregulating N-cadherin and vimentin proteins through the suppression of their transcriptional repressor ZEB-1, and arresting epithelialto-mesenchymal transition (EMT) processes. It also caused induction of the ZEB-1 repressor miR-200c. In vitro and in vivo tests on human T47D breast cancer cells revealed significant antiproliferative efficacy for the AC ethanolic extract. Inhibiting proliferation by causing cell cycle arrest at the G1 phase, AC also promoted autophagy. Cell cycle-related proteins were found to be expressed at lower levels while transcription factor FOXO1, the autophagy marker LC3 II, and the protein p62 were all expressed at higher levels. By increasing the expression of inositol-requiring enzyme 1-(IRE1), glucose-regulating protein 78 GRP78/Bip, and C/EBP homologous protein CHOP, the extract also caused endoplasmic reticulum stress. In vivo, tumor development was reduced.
(Kino *et al.*, 19981); (Lee *et al.*, 1990); (Jong 1992); (Shiao *et al.*, 1994); (Oh *et al.*, 1998); (Oii & Liu, 2000); (Tzianabos, 2000); (Smith *et al.*, 2002); (Yang *et al.*, 2005; (Ganeshpurkar *et al.*, 2010);	Turkey Tail Mushroom or Tunzhi	*Coriolus versicolor*	*Coriolus versicolor* (referred to as *Trametes versicolor* and *Polyporus versicolor*) (Figure 3) also known as turkey tail or tunzhi in China, has long been regarded as a "magic herb" in Asian countries, particularly China, where traditional formulas based on this mushroom are still frequently used to support longevity, vigor, and good health. In China, its medicinal benefits were documented in the "Compendium of Materia Medica" and "Shen Non-Compendium Medica" thousands of years ago. Today, since 1987, *C. versicolor* extracts have been authorized for use in routine clinical practice in both China and Japan, particularly in integrated cancer therapy when

(Fritz *et al*., 2011); (Lu *et al*., 2011); (Ito *et al*., 2012); (Wang *et al*., 2015); (Xu *et al*., 2016); (Chang *et al*., 2017); (Saleh *et al*., 2017); (Rodríguez-Valentín *et al*., 2018); (Venturella *et al*., 2021)			combined with chemotherapy or radiotherapy. At least 12 *C. versicolor*-based medications have currently been given the go-ahead for clinical usage in China by the State Administration of Food and Drugs (SAFD). The polysaccharide peptide (PSP), extracted from the deep layer cultivated mycelia of the COV-1 fungal strain and used most frequently in China, and the glycoprotein PSK (krestin), derived from the strain CM101 and most frequently used in Japan, are two protein-bound polysaccharides present in the fungal extract that give rise to the immunomodulatory properties of this mushroom. They are among the most researched mushroom bio-compounds and are primarily made up of -glucans. Mycelia or even basidioma are boiled in water to extract PSP, which is then precipitated in ethanol. Mannose, xylose, galactose, and fructose make up the carbohydrates in this protein-bound polysaccharide, which has a molecular weight of about 100 kDa, a polysaccharide-to-peptide balance of 90–10%, and a high-water solubility. According to numerous in vitro and in vivo studies, as well as some clinical trials, PSP has immunomodulating, antitumor, anti-inflammatory, and antiviral effects. It has also demonstrated other physiological effects, such as liver-protecting, system-balancing, antiulcer, anti-aging, learning, and memory-enhancing properties, as well as lowering adverse events related to chemotherapy and radiotherapy treatments. The ability to act on cytokine release, to increase the expression of cytokines and chemokines like tumor necrosis factor-α (TNF-α), interleukins (IL-1β and IL-6), histamine, and prostaglandin E, c to activate natural killer (NK) cells, and to enhance dendritic and T cell infiltration into tumors are all factors that contribute to the immunomodulatory activity. These effects are a result of the polysaccharide's β-glucan component, which has been shown to stimulate a variety of immune cells that express the appropriate receptors, including dectin-1, toll-like receptors TLR-2, TLR-4, and TLR-6, and CR3 complement receptors. PSP lowers the Bcl-2/Bax ratio and mitochondrial transmembrane potential, releases cytochrome c, and activates caspase-3, -8, and -9 in human promyelocytic leukemia HL-60 cells to cause apoptosis. Studies using mouse models in vitro have revealed a rise in lymphocyte proliferation and immunoglobulin IgG levels, pointing to impacts of PSP on humoral immunity. Other findings point to a role for PSP in the activation of multiple pattern recognition receptors (PRRs), which is crucial for the innate immune response when a pathogen-associated molecular pattern (PAMP) is encountered. Toll-like receptors, which serve as the body's first line of defense and on which the PSP can have a beneficial effect, are one form of PRR whose precise level of activation depends on the pathogen causing the infection. This type of antiviral activity was demonstrated in vitro by Rodrguez-Valentn *et al*., who found that PSP upregulated TLR4expression in addition to downregulating viral replication and promoting the upregulation of specific antiviral chemokines like RANTES, MIP-1/α/β, and SDF-1α with blocking action on HIV-1 coreceptors in THP1 cells and human peripheral blood mononuclear cells (PBMCs). A study led by Wang *et al*. in mice carrying a normal or defective TLR4 gene observed how PSP stimulates the expression of both cytokines and TLR4 and its downstream signaling molecule TRAF6 and increases the phosphorylation of the transcription factors NF-$_{k}$B p65 and the activator protein AP-1 transcription factor component c-Jun in peritoneal macrophages from TLR4+/+ mice but not from TLR4-/mice. This demonstrates

			that the TLR4 signaling pathway is involved in the immunomodulatory effects of PSP. In addition, a decrease in tumors was observed in comparison to standard saline therapy. Numerous in vitro studies using a variety of models (human PBMCs from cancer patients or healthy individuals, murine splenic lymphocytes, primary mouse peritoneal macrophages, etc.) have demonstrated that PSP treatment increases levels of TNF-α and the cytokines associated with it, IL-1β (the proinflammatory signal that enhances lymphocyte proliferation), but also IL12 (enhancer of NK and CD8+ T cell activity and inducer of interfere on IFN-γ), IL-6, and Il1α, affecting the expression of many other pleiotropic cytokines, e.g., transforming growth factor (TGF)-β (proinflammatory effects on monocytes and Th17 cells; anti-inflammatory effects on B cells and regulatory T cells (T(regs)) and the activation of macrophages, and it also induces superoxide dismutase (SOD) and increases the sensitivity of immune cells to other stimuli. A 100 kDa proteoglycan called PSK has a polysaccharide-to-peptide ratio of 40–60%. Mannose, xylose, galactose, arabinose, and rhamnose are the carbohydrates. Its activities and processes, which were once more shown in vitro or using mouse models, are comparable to PSP because it is similarly primarily constituted of -glucans. On cancer cells in vitro, Krestin demonstrated both direct and indirect lethal effects. The anticancer activity of this drug is mediated by TLR2 in mice, as demonstrated by Lu *et al*. in their in vitro work on splenocytes from neu transgenic mice and in animals expressing a faulty TLR2 gene. It improved DC maturation (CD86+ MHCII; higher levels of IL-12p40 and IL-12p70 were observed, as well as the suppression of tumor growth. It also raised dendritic cells (DC)s and CD4+ and CD8+ T cells, decreased B cells, induced the secretion of Th1 cytokines and IL-2, increased IFN-γ levels, and induced the secretion of Th1 cytokines and IL-2. Similar findings have been reported by other studies, including the activation of cytotoxic T cells (TC cells), improved DC maturation, increased production of IL-8 and other cytokines (TNF-α, IL-1, IL-4, IL-6, and IFN-γ), enhanced MHC class I expression by tumor cells, inhibition of tumor growth, and a decrease in tumor growth factor-β (TGFβ) in vitro. PSK can thereby enhance the body's built-in immune system. This molecule was demonstrated to reduce plasma triglycerides (TGs) and free fatty acids, to downregulate the expression of the proinflammatory factors IFN-γ, IL-6, and IL-1β, and to upregulate the expression of the anti-inflammatory factor IL-10 in a study on mice. It was also shown to improve insulin resistance and hyperlipidemia. So, PSK might be a crucial adjuvant in the control of cardiovascular risk associated with hyperlipidemia. The methods of action of these two protein-bound polysaccharides are still not entirely understood, despite the numerous results attained to date. The bioactivity of PSK and PSP may also be influenced by the peptide component. The mushroom *Trametes versicolor* has produced the protein-bound polysaccharides PSK (Krestin) and PSP. These substances share a lot of chemical similarities and have molecules that weigh about 100 kDa. The monosaccharide with α [1-4] and β [1-3]-glucosidic links that make up the polysaccharide component have immunomodulating properties.

(Smith *et al.*, 2002); (Kawagishi & Zhuang, 2008); (Kuo *et al.*, 2016); (Kuo *et al.*, 2017); (Spelman *et al.*, 2017); (Li *et al.*, 2018); (Lee *et al.*, 2019); (Chong *et al.*, 2020); (Venturella *et al.*, 2021)	Lion's Mane Mushroom	*Hericium erinaceus*	The erinacines (A-I), a class of cyathin diterpenoids recovered from the mycelium of *Hericium erinaceus* (Figure 3), popularly known as lion's mane or yamabushitake, and the hericenones (C-H), benzyl alcohol derivatives extracted from the fruiting body, are other significant and well-studied bioactive metabolites. Both classes of substances are shown to have neurotropic and neuroprotective effects and are easily able to cross the blood-brain barrier. Both in vitro and in vivo nerve growth factor (NGF) synthesis has been reported to be induced by them. Although it is most frequently used to treat neurological illnesses and cognitive impairment, this medicinal fungus also contains antioxidative, anti-inflammatory, anticancer, immunostimulant, antidiabetic, antimicrobial, hypolipidemic, and antihyperglycemic qualities. It has been established that the primary erinacine group member, erinacin A, has a potent anti-Parkinson's disease protective effect. In a 1-methyl-4-phenyl-1,2,3,6 tetrahydropyridine (MPTP) mouse model of Parkinson's disease, erinacin A reduced MPTP-induced dopaminergic cell loss, oxidative stress-induced apoptotic cell death, and the levels of glutathione, nitrotyrosine, and 4-hydroxy-2-nonenal (4-HNE); it also reversed MPTP-associated motor deficits and decreased the impairment of 1-methyl-4-phenylpyridinium (MPP)-induced neuronal cell cytotoxicity and apoptosis, through an endoplasmic reticulum (ER) stress-sustained activation of the IRE1α/TRAF2, JNK1/2, and p38 MAPK pathways, the expression of C/EBP homologous protein (CHOP), IKB-β, and NF-κB, as well as Fas and Bax. This metabolite was also discovered to be effective against ischemic stroke, as reported in a study on rats where it was found that targeting the p38 mitogen-activated protein kinase (MAPK)/CCAAT enhancer-binding protein homologous protein (CHOP) and iNOS/reactive nitrogen species (RNS) pathways reduced neuronal apoptosis as well as the size of the stroke cavity in the brain. In human gastric cancer TSGH 9201 cells, erinacin A was also found to have strong anticancer action. It did this by significantly increasing apoptosis and phosphorylating the serine/threonine kinase PAK-1 and focal adhesion kinase/protein kinase FAK/Akt/p70S6K pathways. Additionally, it led to an uptick in cytotoxicity and ROS production, a decrease in invasiveness and caspase activation, and an increase in the expression of the tumor necrosis receptor TRAIL. A recent investigation that further clarified its mechanisms verified the potent anticancer impact of this metabolite in vitro in two human colon cancer cell lines (DLD-1 and HCT-116) as well as in vivo in a mouse model. The extrinsic apoptosis activation pathways (TNFR, Fas, FasL, and caspases) were stimulated by the treatment, as were the expression of the antiapoptotic molecules Bcl-2 and Bcl-XL, and the phosphorylation of the stress-responsive JNK1/2, NF-B p50 and p330. It was also shown that histone H3K9K14ac modification mediates the upregulation of death receptor molecules through the JNKMAPK/p300/NF-B pathway; the outcomes of the in vivo assay actually revealed increased levels of histone H3K9K14ac as well as histone acetylation on Fas, FasL, and TNFR promoters. Erinacin C, a different erinacin, is well known for its anti-neuroinflammatory and neuroprotective properties. These effects may be attained by inhibiting the expression of I-B, p-I-B (involved in the upstream NF-B signal transduction cascade), and inducible nitric oxide synthase (iNOS) protein,

			as well as by activating the Nrf2/HO-1 stress-protective pathway. The treatment of human BV2 microglial cells with LPS-induced inflammation resulted in reduced levels of nitric oxide (NO), IL-6, TNF-α, and iNOS, the inhibition of NF-κB expression, and the phosphorylation of IκBα (p-IκBα) proteins, as well as the inhibition of Kelch-like ECH-associated protein 1 (Keap1), and increased nuclear transcription factor erythroid 2-related factor (Nrf2) and the expression of the heme oxygenase-1 (HO-1) protein.

Table 7 List of therapeutic potential of mushrooms

Therapeutic Potential	Description of Therapeutic Potential	Author(s)
Antimicrobial Activity	Multiple drug resistance has so far emerged in human pathogenic microorganisms, which may be related to the usage of commercial antimicrobial medications for infection treatment. This prompted the quest for a novel antibacterial substance. There has been evidence of antibacterial action against a wide variety of pathogenic microbes in the mycelia and fruiting body extracts of a wide range of mushrooms. Mushrooms require antibacterial and antifungal chemicals in order to survive in their natural environment. It is possible to isolate several antibacterial substances from the mushrooms that may exhibit a range of therapeutic effects on human health. *G. annulare* [Fr.] applanoxidic acid isolation against trichophyton mentagrophytes, Glibn exhibits mediocre antifungal activity. A variety of Gram-positive and Gram-negative microbes were resistant to the poor activity of steroidal compounds such as 5aergosta-7,22dien-3b-ol and 5,8 epidioxy-5a,8a-ergosta 6,22-dien 3b-ol that were isolated from *G. applanatum* [Pers.] Pat. The best nutritional supplements, with exceptional medical benefits, are believed to be mushrooms. Some edible mushrooms have the ability to fight against numerous human diseases and are antimicrobial. These were discovered to have anti-bacterial and anti-fungal properties against hardy pathogens. Numerous mushrooms, including *Inonotus hispidus* contains ergosterol peroxide which have been discovered to have antiviral activities in vitro against influenza viruses. Some edible mushroom types in Bangladesh were found to have anti-microbial properties by Chowdhury *et al*. (2015). Against all fungi and bacteria, the zone of inhibition ranged from 7 to 20 mm. Comparing *Lentinula edodes* to other mushroom kinds, the best antibacterial activity was noted. Compared to other microbial isolates, *Saccharomyces cerevisiae* was more susceptible while *Pleurotus aeruginosa* was somewhat resistant. The anti-microbial properties of the culture filtrates from 27 edible mushrooms were examined by Chen and Huang (2010). *Colletotrichum higginsianum* spore germination was entirely stopped by the filtrates of *Clitocybe nuda* and *Lentinula edodes*. Three types of mushroom culture filtrates, including those from *Ganoderma lucidum, Lentinus edodes,* and *Clitocybe nuda*, have the ability to completely prevent the germination of spores in *Alternaria brassicicola*. As a result, the bioactive components found in mushrooms have the potential to become biocontrol agents for a variety of plant diseases. In vitro antibacterial activity was discovered in methanol and acetone extracts of the mushrooms *Cantharellus cibarius, Amanita rubescens, Russula cyanoxantha,* and *Lactarius piperatus*.	(Lindequist *et al*., 1990); (Hirasawa *et al*., 1999); (Smania *et al*., 1999); (Dulger *et al*., 2002); (Ali *et al*., 2003); (Karaman *et al*., 2003); (Smania *et al*., 2003); (Ganeshpurkar *et al*., 2010); (Kosanic *et al*., 2013); (Sharma *et al*., 2014); (Kumar *et al*., 2021)

	According to Menaga *et al*. (2012), bioactive *Pleurotus florida* components can be used in place of conventional treatments like antibiotics. The most effective anti-microbial agents, according to Alves *et al*. (2012), were *Russula delica, Fistulina hepatica,* and *Russula botrytis*. The study came to the conclusion that mushrooms can also be utilized pharmaceutically to treat a variety of illnesses. To meet the rising expectations for food quality and safety, Shen *et al*. (2017) found that mushroom extracts can be used as food additives with antioxidant and antibacterial activity, avoiding the rotting of food products.	
Immunomodulator Activity and Immunotherapy	The immune system is significantly influenced by substances such as proteins, peptides, lipopolysaccharides, glycoproteins, and lipid derivatives. A cell-mediated immune response is not elicited by polysaccharides, which are often T lymphocyte-dependent antigens. There has recently been discussion of specific natural polymeric polysaccharides as effective immunomodulatory substances. The body's defense against infections and the growth of malignancies heavily relies on the immune system. The body's defense mechanisms against viral assault and against malignant tumor cells that arise spontaneously involve a dynamically coordinated interaction of innate and acquired immune responses. Macrophages, neutrophils, natural killer cells, and dendritic cells are all parts of innate immunity, which is controlled by cytokines and the induction of inflammatory and acute phase reactions. Mushroom bioactive polysaccharides are essential for immunomodulation. The structural diversity and variability of these macromolecules contribute to the potential of these bioactive polysaccharides bound proteins to influence immune cells. It is generally recognized that mushrooms are a substantial natural source of immunotherapeutic components. These can be used to treat some immunodeficiency illnesses such cancer, tumors, HIV, and tuberculosis by acting as immune-stimulating and immune-modulating drugs. Bioactive substances that were derived from *Pleurotus* mushrooms have the power to boost or stabilize the immune system in people. Polysaccharide-proteins, polysaccharopeptides, functional proteins (ubiquitin-like peptide, ubiquinone-9, glycoprotein, and nebrodeolysin), proteoglycans, and glucans are some examples of these bioactive substances. By promoting (in vitro) the maturation of immune cells in the human immune system, proteins derived from *Ganoderma lucidum* and lectins, the sugar-binding proteins from edible mushrooms, have the ability to modify the immune system of humans. According to Guggenheim *et al*. (2014), mushrooms have an immunomodulating effect that causes tumors to vanish. The mobility of NK (natural killer) cells in mice has been shown to increase when white button mushrooms are consumed. NK cells, a crucial component of the immune system, are in charge of anti-viral and anti-tumor defense. Better production of IFN-g and TNF-a can be used to counteract the enhanced NK activity. Consuming *Agaricus bisporus* (white button mushrooms) changed the way the body responded in favor of T-helper 1, and there is a propensity for increased IL-2 and lymphocyte production. Although mushrooms are incredibly nutritious and may have medicinal effects, there are some drawbacks that prevent them from being widely consumed by all segments of society. All edible mushrooms contain a substance called "trehalose," which some people are sensitive to or allergic to. The enzyme trehalase, which breaks down this sugar, is altered dominantly via autosomal transmission, which results in this intolerance. These have also been linked to an increased risk of Crohn's disease, a long-term inflammatory condition of the digestive system. *Agrocybe aegerita* has a fatal protein that is connected to hepatotoxicity, according to Jin *et al*. (2014). This is because *A. aegerita* has a lectin that is resistant to being broken down by digestive enzymes in the human intestinal tract.	(Chihara, 1992), (Wang *et al*., 1996); (Arola *et al*., 1999); (Hobbs, 2000); (Ooi & Liu, 2000); (Wu *et al*., 2007); (Cui *et al*., 2009); (Petermann *et al*., 2009); (Ganeshpurkar *et al*., 2010); (Oloke & Adebayo, 2015); (Kumar *et al*., 2021)

Antibacterial Effect	Polyacetylene compounds with antibacterial characteristics are primarily found in the genera *Aleurodiscus, Clitocybe, Marasminus, Polyporus, Tricholoma*, etc. *Agaricus bisporus* was reported to have antibacterial properties and quinoid and phenolic derivatives in antibacterial activity in the genera that parasitize trees, such as *Fomes, Ployporus* and *Trametes*.	(Kakraliya, 2020)
Anti-fungal Effect	Sparossol produced by *Sparassis ramosus, Lentinus edodes, cortenellin, Coprinus comatus,* and *Oudemansiella mucida* are a few edible fungi that have anti-fungal properties.	(Kakraliya, 2020)
Anti-Protozoa Effect	*Omphalotus olearius* is a poisonous fungus that contains Terpenoid illudin M and S, which is said to be effective against *Plasmodium gallinaceum*. Protozoan were successfully eradicated by Irpex flavous.	(Kakraliya, 2020)
Antiviral Effect	*Ganoderma nutriceuticals* have shown positive antiviral benefits against Epstein-Barr vims, hepatitis B, and anti-HIV. It has been discovered that a polysaccharide fraction from *L. edodes* is effective against influenza both in vivo and in vitro.	(Kakraliya, 2020)
Anti-Tumor Effect	The anti-tumor compound calvacin is derived from the enormous puffball *Calvatia gigantea*. Calvacin is a non-diffusible basic microprotein, as evidenced by its chemical makeup. The edible mushroom *Boletus edulis* possess anti-tumor properties. The polysaccharide Lentinan can be found in *Lentinus edodes*, *Pleurotus ostreatus* and it is one of the chemical substances that mushrooms have produced that have anti-tumor properties. Flammulin from *Flammulina velutipes*, the acid protein from *Poria corticola* and quinoid from *Agaricus bisporus* have all been shown to contain numerous immune-regulating chemicals. *Ganoderma lucidum* is known as the lifespan mushroom because of these components. It has been demonstrated that maitake (*Grifola frondosa*) has a more potent anticancer and anti-tumor activity.	(Kakraliya, 2020)
Antioxidant Activity	By virtue of its oxidation capabilities, oxygen plays a crucial part in biological processes such as the uptake of nutrients, the movement of electrons for ATP generation, and the elimination of xenobiotics. In the body, oxygen is transformed into reactive forms such superoxide radicals [O_2], hydroxyl radicals [OH], and H_2O_2 that have the ability to damage DNA. These forms of oxygen can also disrupt structural proteins and enzymes, which can result in autooxidation or lipid peroxidation. Antioxidant substances that could halt the harmful oxidative process within the organism have been discovered in mushrooms. Different food kinds contain antioxidant elements that have the ability to snare free radicals and prevent the oxidative alterations that lead to various degenerative diseases. Whole grains, vegetables, fruits, spices, tea, and herbs all contain natural antioxidants. Mushrooms have also been touted as a significant source of antioxidant components due to their phenolic components and other polysaccharides. By boosting antioxidant defenses, dietary supplements of edible mushrooms can minimize oxidative stress. Both cultivated and wild mushrooms exhibit strong antioxidant properties, which are primarily brought on by bioactive substances such polyphenolic compounds, carotenoids, polysaccharides, and vitamins. Edible mushrooms are used as common delicacy meals because they contain antioxidants and other health-promoting ingredients. Mushroom cell wall polysaccharides were shown by Liu *et al.* (1997) to have strong antioxidant capability and to scavenge free radicals in vitro. The methanolic extract was made by Chowdhury *et al*. (2015) by combining a sample of fine-dried mushroom powder (100 g) with 100 mL of methanol at 25°C and 150 rpm for 24 hours, then filtering through Whatman no. 4 paper. After extract analysis, we discovered that the most bioactive substances in extracts	(Halliwell, 1994); (Bijalani, 1995); (Hemnani & Parihar, 1998); (Mau *et al*., 2005); (Dubost *et al*., 2007); (Wei, 2008); (Ganeshpurkar *et al*., 2010); (Mehra *et al*., 2020); (Kumar *et al*., 2001)

	of mushrooms' fruiting bodies are total phenolic components, quantified as mg GAE/g of the fruiting body. It was discovered that phenolic components ranged from 3.2-10.7 mg GAE/g. Flavonoid concentrations in the extract ranged from 2.5 mg/mL to 4.8 mg/mL, and vitamin C concentrations ranged from 0.06 mg/mL to 0.21 mg/mL. With the exception of oyster mushrooms (*Pleurotus ostreatus*), all of the isolates had high phenol and flavonoid levels; however, ascorbic acid was only present in trace amounts. The in vitro antioxidant activity of various edible mushrooms, including *C. cibarius, A. rubescens, L. apparatus*, and *R. cyanoxantha*, was assessed by Kosanic *et al*. (2013). They came to the conclusion that, when compared to other extracts, the acetone extract of *Russula cyanoxantha* mushrooms had the highest antioxidant activity. As a result, including mushrooms in your diet regularly as a source of natural antioxidants may help prevent or lessen oxidative damage and associated lifestyle diseases.	
Anticancer/ Anticarcinogenic Activity	Recent efforts by the National Cancer Institute (NCI US) to find new sources for drugs have focused on natural products such plants, marine species, and microorganisms. In order to research the anticancer efficacy of several plant medicines, NCI began screening them in 1956. Natural compounds derived from plants and their derivatives are currently available and therapeutically helpful anticancer medicines. A huge and mostly unexplored supply of potent novel medicinal medicines comes from mushrooms. They are a never-ending source of polysaccharides with anticancer and immune-stimulating qualities. Instead of directly attacking cancer cells, the polysaccharides in mushrooms cause anticancer effects via triggering various immune responses in the host. These polysaccharides' anticancer effects require a T-cell component, and their activity is mediated by an immune system that depends on the thymus. Both biological characteristics and biotechnological accessibility are important for this application. The body's defense against infections and the growth of malignancies heavily relies on the immune system. The body's defense mechanisms against viral assault and against malignant tumor cells that arise spontaneously involve a dynamically coordinated interaction of innate and acquired immune responses. Macrophages, neutrophils, natural killer cells, and dendritic cells are all parts of innate immunity, which is controlled by cytokines and the induction of inflammatory and acute phase reactions. Mushroom bioactive polysaccharides are essential for immunomodulation. The structural diversity and variability of these macromolecules contribute to the potential of these bioactive polysaccharides bound proteins to influence immune cells. Numerous bioactive compounds with potential anticancer effects are found in medicinal mushrooms. Dietary fiber, polysaccharides, complexes of polysaccharides and proteins, steroids, terpenoids, phenolics, and specific types of proteins are among these substances. Different cancer cell lines were used by Daba and Ezeronye (2003) to investigate the anti-tumor effects of fruit bodies and mushroom mycelial extracts. Mushroom polysaccharides shown possible anti-tumor efficacy against leukemia L-1210, mammary adenocarcinoma 755, and sarcoma 180. Patel and Goyal (2012) reported that the mushrooms possessing anti-carcinogenic characteristics are from genus *Pleurotus, Phellinus, Agaricus, Clitocybe, Ganoderma, Trametes, Antrodia, Xerocomus, Cordyceps, Schizophyllum, Calvatia, Flammulina, Inonotus, Suillus, Albatrellus, Inocybe, Funlia, Russula, Lactarius,* and *Fomes*. Mushrooms contain substances with anti-cancer properties that are important as reactive oxygen species (ROS) inducers, anti-mitotic, mitotic kinase inhibitors, topoisomerase inhibitors, and inhibition of angiogenesis causing apoptosis of cancer cells, ultimately preventing cancer proliferation. *Phellinus linteus* was found to have anti-tumor, immune-modulating, and anti-metastasis activities, according to Baker *et al*. (2008). On colon cancer HT-29 cells, *Pleurotus ostreatus* polysaccharide aqueous extract had pro-apoptotic and anti-proliferative properties. The anti-carcinogenic efficacy of polysaccharides isolated from edible mushrooms was further demonstrated by the polysaccharide from *Agaricus blazei*, which reduced angiogenesis in	(Dai & Xu, 1998); (Hobbs, 2000); (Ooi & Liu, 2000); (Wasser, 2002); (Lavi *et al*., 2006); (Ajith & Janardhanan, 2007); (Niu *et al*., 2009); (Ganeshpurkar *et al*., 2010); (Kumar *et al*., 2021)

	vivo. *Pleurotus pulmonaris, Phellinus rimosus, Pleurotus florida,* and *Ganoderma lucidum*, four medicinal mushrooms from South India, were discovered to have strong antioxidant and anti-tumor properties. These are rumored to be beneficial sources of antioxidant and anti-tumor compounds, as well as having possible anti-mutagenic and anti-carcinogenic properties. According to both in-vivo and in-vitro research, button mushrooms (*Agaricus bisporus* L.) have a high potential for lowering breast cancer because of their ability to reduce aromatase activity and oestrogen production. In Korea, Shin *et al*. (2010) investigated the role of mushroom consumption in reducing the risk of breast cancer in 358 women and 360 cancer-free (control) women. They came to the conclusion that higher mushroom consumption was associated with a lower risk of breast cancer in premenopausal women. They also noticed that women with malignancies that express hormone receptors may be more likely to experience this relationship. Different cancer cell lines were used by Daba and Ezeronye (2003) to investigate the anti-tumor effects of fruit bodies and mushroom mycelial extracts. Mushroom polysaccharides demonstrated potential anti-tumor action.	
Hypo-Cholesterolemic Agents	Hypercholesterolemia, low-density lipophilic oxidation, and atherosclerosis are associated with cardiovascular diseases. As a result, controlling blood cholesterol levels is necessary for both treating and preventing this disease. The best diet for preventing heart diseases is edible mushrooms because of their high fiber and low-fat content. In oriental medicine, eating more edible mushrooms is frequently advised as a natural hypocholesteromic and anti-sclerotic diet. The use of Termitomyces microcarpus mushrooms has been found to significantly reduce the incidence of blood lipid-related diseases, and it has also been suggested that the mushrooms' high fiber content can lower total serum cholesterol, LDL-cholesterol, and triglycerides. Exo-polymers produced in the submerged culture of *Grifola frondosa* (GF), *Flammulina velutipes*, *Hericium erinaceus*, *Phellinus pini*, and *Auricularia auricula-judae* show a hypolipidemic effect on the test animals. Eritadenine [2(R), 3(R)-dihydroxy-4- (9-adenyl)-butyric acid], an active hypo-cholesterolemic component, was extracted and discovered by Rathee *et al*. (2012) in the shiitake mushroom. Eritadenine can lower blood cholesterol levels in mice by accelerating the metabolic breakdown and excretion of ingested cholesterol.	(Ishikawa *et al*., 1984); (Yang *et al*., 2002); (Nabubuya *et al*., 2010); (Kumar *et al*., 2021)
Hepatoprotective Effects	Hepatocellular carcinoma, cirrhosis, fibrosis, and chronic hepatitis are the hallmarks of liver damage, which is mostly brought on by oxidative stress. Hepatotoxicity, which results in damage to the liver and decreased liver function, can be brought on by the consumption of any medicine or by a variety of non-infectious substances. Similar to this, an ethanolic extract from *Calocybe indica* has been shown to protect against the hepatotoxicity caused by carbon tetrachloride in mice. This extract has been shown to have a protective effect against the damage to the liver caused by the poisoning. When tested with the galactosamine-induced cytotoxic test, ganoporeric acid A, ganoderic acids R and S, and *Ganoderma lucidum* extract all had in vitro anti-hepatotoxic effects on primary cultured rat hepatocytes. Alanine transaminase and aspartate transaminase levels were found to be significantly reduced by extracts from the basidiomass of *Ganoderma frondosa* and *Lentinus edodes* (100 mg/kg of body weight), while *Tricholoma lobayense* mycelial aqueous extracts had hepatoprotective effects at higher doses of 300 mg/kg of body weight. In a study conducted on albino rats, Sumy *et al*. (2014) investigated the hepatoprotective properties of *Pleurotus florida* against the damage brought on by the consumption of paracetamol. The outcomes of the experiment revealed significant antioxidants as well as hepatoprotective properties of the ethanolic extract of the mycelium of *Morchella esculenta*. The fungus variation *Ganoderma lucidum* has been widely examined and has been found to have strong hepatoprotective properties. Tri-terpenoids, polysaccharides, ergo-sterols, nucleosides, proteins, peptides, fatty	(Hirotani *et al*., 1986); (Kodavanti *et al*., 1989); (Ooi, 1996); (Kim *et al*., 1999); (Zhou *et al*., 2002); (Navarro *et al*., 2006); (Refaie *et al*., 2010); (Chatterjee *et al*., 2011); (Chen *et al*., 2012); (Zhang *et al*., 2012); (Soares *et al*., 2013); Kumar *et al*., 2021)

	acids, and trace elements are only a few of the 400 chemical compounds isolated from *Ganoderma lucidum* that exhibit hepatoprotective properties. Triterpenoid and polysaccharides were discovered to be possible bioactive elements among them, with a notable protective effect against liver harm brought on by a variety of toxins. Triterpenoids have the ability to reduce-glucuronidase activity, which measures the severity of liver damage. Rats exposed to carbon tetrachloride did not suffer from liver damage thanks to insoluble non-starch polysaccharides isolated from *Pleurotus ostreatus* mycelium. Using polysaccharopeptides obtained from *Pleurotus ostreatus*, hepatic damage brought on by thioacetamide poisoning in mice can be avoided. When used as a supplement, polysaccharides from *Hericium erinaceus* can be used to prevent a number of liver illnesses. An essential functional food additive, *Pleurotus eryngii*'s polysaccharide-rich extract has been shown to have hepatoprotective and hypolipidemic properties. *Agaricus blazei* extracts have demonstrated comparable efficacy in the treatment of paracetamol-induced liver damage.	
Anti-Diabetic Effects	Diabetes mellitus is a metabolic condition that can be managed with better living conditions, regular exercise, and a healthy diet. Mushrooms can be useful foods for managing diabetes. These are great sources of biologically active substances with anti-diabetic effects. Numerous types of mushrooms are very good at regulating blood sugar levels and managing diabetic issues. Numerous studies have suggested that certain types of mushrooms, including *Agaricus subrufescens, Agaricus bisporus, Coprinus comatus, Cordyceps sinensis, Inonotus obliquus, Ganoderma lucidum, Pleurotus spp., Phellinus linteus, Sparassis crispa,* and *Poria cocos*, have hypoglycemic properties. The edible mushrooms are regarded as low-calorie foods for diabetic people because they have very low levels of fat, cholesterol, and carbs and are high in protein, vitamins, and minerals. Mushrooms are the best sources of herbal remedies with anti-diabetic properties, according to Kaur *et al*. (2015). These are regarded as functional foods and a large source of bioactive substances, including proteins, lipids, and polysaccharides, as well as metabolites with high therapeutic activity, including alkaloids, terpenoids, lactones, lectins, sterols, and phenolic compounds. In the exopolysaccharides produced in the submerged culture of *Tremella fuciformis* in ob/ob mice, Cho *et al*. (2007) found anti-diabetic properties. The hypoglycemic properties of a methanolic extract from *Pleurotus citrinopileatus* were investigated by Rushita *et al*. (2013) against streptozotocin-induced type-2 diabetes mellitus in rats. The fasting blood glucose level and serum catalase activity both significantly decreased, but the serum insulin level significantly increased in the groups treated with a high dose of mushroom extract compared to the control group. Mushrooms contain a significant carbohydrate called β-glucan in large amounts. It has been discovered to improve insulin secretion by β-cells, which lowers blood glucose levels while repairing the functions of pancreatic tissues. In the pancreatic tissues of rats, lectins isolated from *Agaricus campestris* and *Agaricus bisporus* stimulated the release of the hormone insulin from the islets of Langerhans. In mice with alloxan-induced diabetes, the ethanolic extract of *Pleurotus ostreatus* significantly lowered the serum glucose level. In the post-treated groups, serum concentrations of urea and creatinine dramatically decreased. *Pleurotus ostreatus* was discovered to be useful in diabetic mellitus treatment preparations.	(Ahmad *et al*., 1984); (Cui *et al*., 2009); (De Silva *et al*., 2012); (Ravi *et al*., 2013); (Kumar *et al*., 2021)

Table 8 List of Environmental Contributions of Field Mushrooms

Environmental Activity	Description of Environmental Activity	Author(s)
Soil Erosion Control	In locations prone to excessive rainfall, soil erosion is a major factor contributing to poor soil health and loss of agricultural output. As a result, erosion control is still a top priority in landscape management, and many engineering and agricultural techniques have been created and put to use to reduce soil erosion. These might be enumerated in the following order: stabilizing soil aggregates; terracing in mountainous terrain; and conservation tillage. Reducing the impact of rainfall through the use of shade cloth and forest canopy. Additionally affordable and useful for controlling soil erosion are biological methods. Enhancing the amount of fungal mycelium in agricultural soils, with mushrooms as a result, is a potential alternative. Both direct and indirect techniques can help soil erosion management when mushrooms are grown in agricultural fields. In the direct mechanism, the formation of soil aggregates is facilitated by the binding of soil particles by mushroom mycelia and the development of robust cord-forming mycelial networks. In the indirect route, fungal hyphae release hydrophobins like glomalin and other extracellular substances into the soil, boosting soil organic matter. These substances include mucilages and polysaccharides. As a result, soil aggregate clumps are formed by the combination of fungi, organic matter, nutrients, water, lipids, protein, and minerals which prevents soil erosion.	(Tisdall, 1994); (Mortimer *et al.*, 2008); (Caesar-TonThat *et al.*, 2013); (Vaezi *et al.*, 2017); (Lotfalian *et al.*, 2019); (Ravi *et al.*, 2019); (Seitz *et al.*, 2019); (Hu *et al.*, 2021)
Cord-Forming Mycelial Network	The majority of mushroom species chosen for outdoor cultivation are saprophytic fungus, meaning they survive by feeding on organic waste found in soil or compost layers. A few micron-diameter spore is the first stage of a mushroom's life cycle. In a moist, nutrient-rich environment termed a hypha, the spore expands, germinates, and elongates to create a filamentous cell. The hypha lengthens as it develops into a network of interwoven hyphal threads known as a mycelium. The mycelium runs in the compost during the field-based mushroom cultivation process to gather nutrients and finally create the "cord-forming mycelial network." The mycelia spread into the soil layers once the fungal mycelial network has completely colonized the compost layer, absorbing nutrients and carbon from the soil and releasing fungal-based organic matter into the soil. Mushrooms can grow thanks to the mycelia's uptake of carbon and nutrients. The hyphal networks can chemically or physically bind soil particles, assisting in the production of soil aggregates when the fungal hyphae penetrate the soil layers. These duties are carried out by two field-cultivated mushrooms, *Phallus impudicus* and *Stropharia rugosoannulata*. According to studies by Thompson and Rayner (1983) and Donnelly and Boddy (2001), *Phallus impudicus* grows in the field and forms mycelial networks that resemble cords. Similar observations were made when *Stropharia rugosoannulata* was grown in the field: following the process, a lot of hyphae were found in the soil. The aggregation of soils is improved and overall soil quality is raised by the rising number of hyphae in soils, particularly core-forming mycelial networks. The ability of roots to penetrate the soil systems is enhanced by soil aggregation, which also promotes gaseous flow within the soil and lessens soil erosion. Furthermore, aggregates act as homes for microbial dynamic processes as soil carbon sequestration, microbial evolution, nutrient cycling, and trace gas emissions.	(Blanco-Canqui & Lal, 2004); (Helgason *et al.*, 2010); (Sanchez,2010); (Lehmann *et al.*, 2017); (Rilling *et al.*, 2014); (De La Porte *et al.*, 2020); (Meyer *et al.*, 2020); (Hu *et al.*, 2021); (Yang *et al.*, 2021)
Soil Organic Matter	Increasing soil organic matter levels is a significant strategy for reducing soil erosion. Higher organic carbon content soils provide good erosive protection. Due to their potential to boost soil fertility and soil organic matter, conservation tillage and organic farming can assist to minimize soil erosion. Organic matter binds soil particles and raises the soil's moisture	(Casermeiro *et al.*, 2004); (Mohammad &

	content, preventing soil from drying out and prevents soil particles from being swept away during heavy rain or high winds. The growth of soil structure, water-storage capacity, formation of aggregation, biota biomass, and biodiversity in soil ecosystems are encouraged by an increase in organic matter. According to research, field-based mushroom growing is a successful method for increasing the amount of organic matter in soils, either by incorporating compost and discarded mushroom substrates into the soil or by adding organic material that is based on fungi (mycelium, hyphal exudates). Utilizing agricultural waste, such as crop residues for compost production ensures a circular system and reduces the use of additional external resources to be used for mushroom production. Compost used in field-based mushroom cultivation can support sustainable production systems. Compost from mushroom culture serves as a growth medium for mushroom hyphae and cord-forming mycelia that can colonize soil systems during the cultivation process. While the majority of the mycelia is in the soil and does not contribute to the development of mushroom fruiting bodies, when this portion dies and is replaced, the amount of organic matter in the soil rises. *Stropharia rugosoannulata* was used in culture research by Gong *et al*. (2018) that revealed soil organic matter considerably increased following *S. rugosoannulata* cultivation compared to soil systems not subjected to compost-based mushroom growing under field circumstances. Additionally, intercropping *S. rugosoannulata* and citrus trees greatly increased soil organic carbon, a crucial criterion for determining the quality of the soil in agroforestry systems. Mushroom substrate materials like crop straw or woodchips have been found to enhance soil organic matter and soil mineral nutrition in addition to the organic matter created from fungal mycelium. For instance, Lou *et al*. (2017) research showed how organic matter from discarded mushroom substrates is transformed into humus in the soil, increasing the amount of organic matter within. Tan *et al*. (2019) investigation focused on the nutritional acquisition of morel mycelium from exogenous nutrient bags through soil medium. Tan *et al*. examined the field growing procedures of *Morchella importuna* (Black morel). The exogenous nutrient bags were broken down by *M. importuna* mycelia during the cultivation phase, which resulted in a considerable rise in the surface soils' soil organic carbon content. These studies offer convincing evidence that increasing soil organic matter levels and reducing soil erosion can both be accomplished by field-based mushroom cultivation of a variety of species.	Adam, 2010); (Machmuller *et al*., 2015); (García-Díaz *et al*., 2016); (Keesstra *et al*., 2016); (Zhang *et al*., 2017); (Gobbi *et al*., 2018); (Seitz *et al*., 2019); (Hu *et al*., 2021)
Carbon Cycling	The predominant form of carbon in the majority of agricultural waste substrates utilized in field mushroom production is fermentable sugar, like lignin, hemicelluloses, and cellulose. Lignocelluloses are broken down by extracellular enzymes like lignin peroxidases, manganese peroxidases, and versatile peroxidases after the inoculation of compost and mushroom spawn. The carbon cycle plays a significant role in several tight interactions between soil layers and the layer responsible for mushroom cultivation in fields. Physical processes including weathering and leaching transport carbon, primarily microbial carbon, from the growing substrate to soil during the mushroom farming process. The amount of organic matter in in situ soil rises when spent mushroom substrate is employed as a bio-fertilizer. Additionally, spent mushroom substrate can be used to make biochar, which can then be reintroduced into soil systems. As seen above, there are four main pathways by which the metabolites of carbon sources are transported: 1) mycelium biomass conversion and fruiting body formation; 2) carbon dioxide emissions from the respiration of mushroom mycelia and other microbes; 3) involvement in the formation of humus in the soil; and 4) microbial carbon and lignocelluloses present in spent mushroom substrates.	(Anastasi *et al*., 2009); (Major *et al*., 2010); (Anasonye *et al*., 2015); (Czop & Pikoń, 2017); (Pérez-Chávez *et al*., 2019); (Zhao *et al*., 2019); (Hu *et al*., 2021)

Nitrogen, Phosphorus, Potassium Cycling	We rely on findings from research using discarded mushroom substrates as compost for agricultural fields because there is currently a dearth of information on the direct influence of field-grown mushrooms on soil nutrition. Composted spent mushroom substrates can be used to agricultural areas to enhance the nutrition and wellness of the soil, according to Lou *et al*. (2017) research. In fields composted with used mushroom substrates, the authors reported a larger than 5-fold increase in soil mineral nitrogen. Similar to this, Yu *et al.* (2019) discovered high amounts of soil organic matter and readily available nitrogen, phosphate, and potassium in agricultural fields treated with wasted mushroom substrates. These results do show the potential of mushroom compost for enhancing soil nutrient content, even though they are not directly related to field-based cultivation experiments.	(Hu *et al*., 2021)
Degradation of polycyclic aromatic hydrocarbons	Polycyclic aromatic hydrocarbons (PAHs) are organic-based contaminants that are prevalent in soils and typically result from anthropogenic activities like pesticide use on agricultural areas and petroleum-refining operations as well as natural emissions from wood fires and volcanic eruptions. As mutagenics, teratogens, and carcinogens, PAHs pose a concern to human health in soil ecosystems. Immune system disorders, both acute and chronic, may be brought on by PAH exposure. Even though PAHs are hydrophobic and are primarily found on particulate matter, they impair crop yield and get into our food through the food web. PAHs are resistant to environmental deterioration because of their chemical structure and limited solubility. Due to the distinctive extracellular enzymes released by fungal hyphae, fungi are promising species that can digest PAHs in soil ecosystems. The catalytic breakdown of hydrocarbons in agricultural lands is facilitated by the establishment of considerable mushroom mycelia throughout the soil that are made possible by field mushroom cultivation. These mycelia produce a large quantity of enzymes including laccases and peroxidases that help this process. The microbial-substrate based remediation method and the phyto-microbial remediation method are the two primary bioremediation strategies for refractory hazardous PAHs. By lowering the PAH level in agricultural soil ecosystems, field mushroom cultivation, also known as the fungi-substrate approach, can improve soil health. For instance, bio-stimulation and bioaugmentation caused by the use of *Agaricus bisporus* waste mushroom substrate can degrade PAHs; prior studies have shown that the inclusion of spent mushroom substrates stimulates the growth of resident soil bacteria and eliminates 3-ringed PAHs. Benzo[a]anthracene, benzo[a]pyrene and dibenzo[a,h]anthracene in soils can be effectively degraded by eight mushroom species (*Agrocybe dura, A. praecox, Hypholoma capnoides, Kuehneromyces mutabilis, Pleurotus ostreatus, Stropharia. coronilla, S. hornemannii, S. rugosoannulata*), and the mycelia of *S. coronilla* and *S. rugosoannulata* grow into the soil and are the most efficient at degrading PAHs. Based on the aforementioned application, it is technically possible to remediate environmental in situ PAH using a combination of fungal species and agro-waste during field mushroom growing.	(Wilcke, 2000); (Antizar-Ladislao *et al*., 2004); (Steffen *et al*., 2007); (Anastasi *et al*., 2009); (Haritash & Kasushik, 2009); (Winquist *et al*., 2014); (García-Delgado *et al*., 2015); (Abdel-Shafy & Mansour, 2016); (Kadri *et al*., 2017); (Marchand *et al*., 2017); (Wang *et al*., 2019); (Hu *et al*., 2021)
Pesticide and herbicide degradation	The worldwide ecosystem is currently heavily populated with chemical pesticides. Environmental risks caused by chemicals from the use of pesticides, herbicides, and fungicides have an impact on the chemistry and biology of the soil. As the usage of mushrooms has garnered significant scientific interest, mycoremediation of contaminated soils is regarded as a viable solution to the current situation. The breakdown of pesticides such endosulfan, lindane, methamidophos, cypermethrin, dieldrin, methyl parathion, chlorpyrifos, and heptachlor is effective with many mushroom species or spent mushroom substrates. Fungal strains have destroyed pesticides by biological processes such oxidation, hydroxylation, and demethylation at both laboratory and field scales with the help of several enzymes. Abiotic variables including pH, temperature, and moisture also have an impact on the rates of deterioration in soils. For example, Ribas *et al*. (2019) discovered that *Agaricus subrufescens* can reduce atrazine, a type of herbicide that causes cancer, by 35% when the pH is at 4.5 and by less when the pH is higher. According to Jin *et al*. (2016) investigation on the microbial	(Ahlawat *et al*., 2010); (Matute *et al*., 2012); (Kaur *et al*., 2016); (Jin *et al*., 2016); (Maqbool *et al*., 2016); (Yadav & Sharma, 2019); (Hu *et al*., 2021)

	degradation of laccase-catalyzed pesticides, pH 5.0 and 25 °C provide the best conditions for laccase activity. Laccase is also stable over a pH range of 5.0–7.0 and a temperature range of 25–30 °C. The soil moisture content was adjusted to 70% to maintain the activity of the spent mushroom substrate microbiota for removing soil contaminants in the experiment conducted by Garcia-Delgado *et al*. (2015). *Agaricus bisporus* substrate was used to remediate polycyclic aromatic hydrocarbons-contaminated soils. The decomposition of endosulfan, a highly toxic organochlorine pesticide, by *Pleurotus ostreatus* and the degradation of the organochlorine-based pesticide Lindane by the white rot fungus *Ganoderma lucidum* are two important instances of pesticide degradation employing fungi in a laboratory setting. This study also shown how effectively lindane was degraded using a dialyzed crude extract of ligninolytic enzymes from mushroom culture. The majority of tests on the biodegradation of pesticides, however, have only been carried out at the lab scale, and the majority of the mushroom species employed for the degradation of pesticides and herbicides are not linked to field-cultivated mushrooms. According to reports, only *Agaricus bisporus* and *A. subrufescens* have the capacity to break down pesticides in natural settings. Metsulfuron methyl is digested by spent mushroom compost enzymes, according to research by Matute *et al*. (2012) utilizing substrate from a spent *A. subrufescens* culture. High laccase activity was also found throughout the experiment. Further proof of the ability of fungi to break down pesticides and agrichemicals was provided by Ahlawat *et al*. (2010) report that the waste mushroom substrate of *A. bisporus* is effective in the degradation of Carbendazim and Mancozeb, two widely used fungicides.	
Bioremediation of heavy metal contaminated soils	Recent studies by Bosco and Mollea (2019) and Raina *et al*. (2020) investigate the mechanisms behind mycoremediation of metal-contaminated soils, offering in-depth analysis of these procedures and highlighting the emerging role that fungi can play in the bioremediation of heavy metal-contaminated soils. A nice illustration of how heavy metals in soil can be reduced under field-based mushroom production can be seen in the work of Stoknes *et al*. (2019). According to the scientists, there is an 80% reduction in Cd levels when Agaricus subrufescens is grown in soil that has been contaminated with Cd. Since the initial batch of mushrooms that were gathered included the majority of the accumulated Cd, those mushrooms had to be thrown away. On the other hand, later mushroom harvests proved to be suitable for human consumption. The wasted mushroom substrate of *Volvariella volvacea*, according to Liaqat (2017) is also a strong option for the bioremediation of Pb- and Hg-contaminated soils. As a result, biosorption in both the cultivation process and discarded mushroom substrates indicates promise for the field mushroom cultivation of mushrooms in the bioremediation of heavy metal-contaminated soils and enhanced soil health.	(Raina *et al*., 2020); (Hu *et al*., 2021)

4.8. Environmental Benefits of Mushrooms

Macro-fungus, sometimes known as mushrooms, has a variety of important environmental functions (Table 8). Mushrooms break down complicated lignin-rich molecules, which in turn causes all lignin-rich organic waste items in the area to disintegrate and create clean environmental conditions. In India, the majority of the leftover wheat and paddy straw is used to produce mushrooms; otherwise, these leftovers are burned in open fields, which significantly damages the environment's air quality. In a specific bioremediation program, several mushroom mycelia are successfully utilized [144].

In managing ecosystems, mushrooms have a significant ecological impact [88] [201]. Indirectly, growing mushrooms is a form of bioconversion, or the conversion of organic materials into new forms, which allows for the recycling of biological waste and so lowers pollution. After the harvest of the mushrooms, materials utilized in mushroom growing are spread as organic manures over the soil. The handling of agricultural and agro-industrial leftovers is a good application for mushroom cultivation [88] [267].f

The majority of mushrooms grow on fallen wood, bark, sap wood, etc., whereas only a small number of species assault living trees. In a few years, the wood completely disintegrates due to the mushroom's mycelium. It gradually combines with the forest soil and gives growing trees sustenance. As a result, mushrooms play a significant role in supplying nourishment to virgin forest. Decomposition of organic matter that has died is one of the important functions that mushrooms perform in natural systems. A series of saprophytic fungus perform the decomposition process. Wood, straw, and other plant matter's lignin and cellulose are broken down by the main decomposers, such as the Shiitake, Oyster, and Wine Cap mushroom (*Stropharia rugosoannulata*), to begin the decomposition process [144].

After the substrate has partially decomposed, secondary decomposers take over. The Portobello and White Button mushrooms (*Agaricus* spp.) are examples of secondary decomposers that generally grow on compost. Typically found on reduced substrates, tertiary decomposers are soil-dwelling organisms. Several *Agaricus s*pecies, the Peel mushroom, *Conocybe*, *Agrocybe*, and *Pluteus* are among them. The primary and secondary decomposers are the most ideal for culture since, with the right methods, there is a high success rate and the mycelium of these species is typically extremely strong. Additionally, substrates are easily accessible. Then, among the natural forces that have improved the state of the planet, mushrooms deserve to be ranked extremely highly [144].

4.9. Ecological Benefits of Mushrooms

All ecological functions are based on biodiversity [31] [74]. Ecosystem health and provisioning are at risk due to the ongoing loss of biodiversity and the acceleration of environmental and global change [74] [242]. It is generally known that greater fungal diversity boosts tree productivity and has a direct impact on "food supply," "biochemicals," "natural medicines," and "pharmaceuticals" [74] [113]. They play a significant ecological role in the breakdown of trash and the recycling of vital nutrients in soil [17] [74]. According to Perez-Moreno *et al*. (2002), one of the most significant mutualistic relationships between plants and fungi is the mycorrhizal connection, which facilitates the exchange and communication of nutrients and minerals.

Every living thing on earth has distinct ecological values. Due to their interdependence within a certain ecosystem, each living thing on earth has a specific function in preserving the ecological balance. By taking part in the breakdown of organic waste, mushrooms contribute to distinct nutrient cycles in different ecosystems. Several plants and trees have symbiotic mycorrhizal associations with a small number of fungi. Numerous wild creatures, such as insects (beetles, flies, gnats, springtails, centipedes, etc.), slugs, squirrels, and deer, depend on wild mushrooms for sustenance [144].

The parasitic mushroom has a negative impact on the ecosystem's health by spreading illness, stunting the growth, and decreasing the fertility of numerous wild floras. Other ecological functions of wild mushrooms include the preservation of soil quality, bioremediation, and pollution reduction. There are still many ecological tasks that mushrooms play that are unknown to this day [144].

Black-cap mushroom *Coprinus comatus* is particularly liquescent and quickly turns into a black liquid that can be used for writing. Flower pots are made from the shaped fruit bodies of *Polyporus fomentarius* and *P. ignitarius* [144]. The ability of microbes, plants, and animals to make light in the dark is well documented. Numerous fungi also have luminous fruit bodies or mycelium, or even both, depending on the species. Woodmen, forestry professionals, lumber workers, and anybody else who needs to navigate a dark forest are familiar with luminous. As long as development continues and the environment is wet, the rotting wood itself is allowed to glow when combined with *Armillaria mellea* mycelium. Another luminous fungus is *Fome anosus*. The mycelium and fruit bodies of this fungus, which is found in mines, are both brightly colored. Light is also produced by *Pleurotus japonicus* [144].

Over half of the climatically determined geographic ranges of 8% of plants, 4% of vertebrates, and 6% of insects will be lost with an average temperature increase of 1.5 °C above pre-industrial levels. For a 2 °C increase in global temperature, these numbers will rise to 16% of plants, 8% of vertebrates, and 18% of insects [74] [127]. Climate change, extensive environmental degradation, such as pollution, habitat loss, and deforestation, have a negative impact on fungi as well [74] [329].

Increasing the likelihood that ecosystems will go extinct, which would significantly reduce their ability to provide the natural resources that local and downstream communities rely on for products and services [74] [122] [162] [217] [275] 276] [208]. The Hindu Kush Himalayan Assessment [74] [331] has emphasized the significance of the mountain ecosystem for achieving Sustainable Development Goal (SDG) 15 # Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and stop, slow, and reverse land degradation and stop biodiversity loss. Additional research in the domains of mycology, silviculture, landscape management, and climate change will shed more light on the potential outcomes and opportunities in FHL. Similar to this, risks related to biodiversity would also be lower at 1.5 °C than at 2 °C of warming, supporting a greater persistence of ecosystem services, such as forest fires, extreme weather events, and the spread of invasive species, pests, and diseases (including soil borne fungal diseases) [74] [127]. Additionally, fungi have been investigated as a confirmed indication of global warming and air pollution [74] [281].

5. Conclusion

This review placed emphasis on mushroom cultivation and production and the variety of benefits and therapeutic potentials. Mushrooms have many roles, importance and benefits such as: economic benefits, medicinal benefits, ecological benefits, environmental benefits and nutritional benefits. Globally, mushroom production is increasing and is making a significant impact on the economy of countries that engage in its cultivation. Mushrooms are cultivated worldwide in both small-scale and large-scale farming, and there are many positive and negative implications regarding mushroom cultivation and production. Additionally, mushrooms play an important role in ecosystems which are on the verge of being affected by climate change. More research should be done when it comes to mushroom cultivation and production, benefits and therapeutic potential. Many of the papers that were availabled and reviewed focused on mushroom cultivation and production, benefits and therapeutic potential external to the Neotropics, hence, more research should be done on mushrooms in the Neotropics.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors hereby declare that this manuscript does not have any conflict of interest.

Statement of informed consent

All authors declare that informed consent was obtained from all individual participants included in the study.

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