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Chapter

Edible Mushrooms, a Sustainable Source of Nutrition, Biochemically Active Compounds and Its Effect on Human Health

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Abstract

Mushrooms are abundant in proteins, polysaccharides, micronutrients, unsaturated fatty acids, and natural compounds. Mushrooms have recently gained popularity as a source of biologically active substances with medical potentials, such as anticancer, antiviral, immune-boosting, hypocholesterolemic, and hepatoprotective agents. Some common edible and helpful mushrooms include *Lentinus* (shiitake), *Flammulina* (enokitake), *Tremella* (yiner), *Herichium*, *Pleurotus* (oyster), *Grifola* (maitake) and *Auricularia* (mu-er). Details on the nutritional content of mushrooms, functional components, and their influence on human health will be explored in this chapter. Mushrooms are used to cure a wide range of ailments. Mushrooms provide a lot of nutrients and are low in calories. They are also fat-free, low in sodium, cholesterol-free, and high in fiber, protein, and antioxidants. They lower the chance of acquiring significant health problems, including Alzheimer, heart disease, and diabetes. It also has antifungal activity. They are also high in selenium and other biochemically active compounds, which have the ability to lower the incidence of chronic illness.

Keywords: mushroom, nutrition, human health, bioactive substance, natural substance, chronic disease, antioxidant, antifungal, antiviral

1. Introduction

Mushrooms have long been regarded as a delicacy item, particularly for their distinct flavor, and have been regarded as a culinary marvel by humans. There are about 2000 types of mushrooms in the environment, but only about 25 are commonly acknowledged as edible and just a few are economically grown. Mushrooms are a delight with excellent nutritious significance, as well as a naturopathic food; they are of significant interest due to their overall acceptability worth, therapeutic characteristics, and financial relevance [1, 2]. Mushrooms are macrofungi that have

unique and apparent fruiting entities that may grow above and below ground [1]. Fungi miss the fundamental property of plants, namely the capacity to effectively consume power from the sun via chlorophyll. They depend on some other beings seeking food, and to get nourishment from the organic matter in which they exist. Mycelium is the fungus's live body, and it is made up of hyphae, which are small webs of threads (or filaments). Digestive products are absorbed by hyphae and can permeate the substrate. Interbreeding hyphae will join and begin to form spores under certain environments. Mushrooms are gigantic entities that produce spores. Since antiquity, many civilizations have utilized mushrooms as a foodstuff and medicinal. The industry has now clearly divided farmed and wild culinary mushrooms, which are utilized direct or indirect as food or ingredients, from medicinal mushrooms [2]. Beneficial mushrooms are commonly used as a meal in many nations. Edible mushrooms are precious constituents of the eating plan due to their appealing flavors, fragrance, and nutritive benefits. Their culinary and advertising value stems mostly from organoleptic qualities like texture and flavor, with edible mushroom species distinguishable based on their strong smell or aroma [3, 4]. Their nutritional benefit arises from their protein content, fiber, vitamin, and mineral composition, as well as their reduced fat content [5–8]. Mushroom peptides have the same amino acid composition as animal protein [9, 10], which is particularly important in light of the large intake of protein from animal dietary sources, particularly in industrialized nations. Furthermore, edible mushrooms encompass a wide variety of beneficial chemicals, eritadenine, and polyphenols, for example [7, 8, 11]. In this frame of reference, the International Life Sciences Institute (ILSI Europe) made available a widely accepted definition of functional food, stating that Food functional” has been shown to have a positive effect on the body, Aside from healthy dietary considerations, in a way that contributes to improved health and well-being and/or a reduced risk of developing the disease [12, 13]. Substantial research has indicated that several mushroom kinds are effective in the therapy of a wide range of diseases [14–16]. That is why edible mushrooms are categorized as a functional food. Mushrooms may be a novel source of antimicrobial chemicals, mostly secondary metabolites for example benzoic acid derivatives, sterpenes, anthraquinones, steroids, and quinolones, as well as oxalic acid, peptides, and proteins. The most researched genus, *Lentinus edodes*, appears to exhibit microorganisms killing both gram-positive and gram-negative bacteria [17].

2. Mushroom cultivation

Vegetable Mushroom cultivation entails a number of various activities, each of which should be properly carried out. The substrate making, inoculation, incubation, and production needs are governed by the mushroom species to be grown. The initial step is to get pure mycelium mushroom strain. Mycelium can be derived via spores, which are part of a specific fungus, or through a variety of germplasm suppliers. Mycelium is cultivated on cereal grains such as wheat, rye, or millet to get inoculum and is referred to as “spawn” [18, 19]. The goal of the mycelium-coated grain is to colonize the selected bulk growth substrate fast. The sustainability of the “spawn,” which must be produced in a clean environment in order to prevent contamination of the substrate, is critical to the success of mushroom cultivation. Several research has been conducted in order to enhance the quality and create new production procedures. *P. Ostreatus* spawn, for example, has indeed been produced in several ways: on grain, wheat, rice, and sorghum are a [20–22], and on grain strewn with grain are few

examples [23–25]. The growth in mushroom output has resulted from more specialized research conducted by a number of international institutes in various areas of mushroom growing. The adoption of DNA-based technologies has sped up breeding processes and will benefit mushroom breeding initiatives [26]. The discovery and identification of genetic markers have resulted in significant advancements in the development of breeding procedures [27]. The study of the biological component of mating-type DNA in strain creation cannot be overstated with excellent yield and tolerance to bacterial illnesses [28, 29], infectious infections [29, 30], and pathogenic organisms [31, 32]. To enhance mushroom cultivation production, it's critical to provide ideal conditions and, if feasible, provide automated monitoring of growth rooms, handling machines, hydroblending, and pre-wet equipment, or other current technology, as well as novel sterile procedures, to continue cultivating mushrooms on a non-composted substrate [33]. A computerized integrated environmental system is a major asset in mushroom cultivation. Environmental characteristics such as temperature, moisture, ventilation, elevation, and CO₂ and oxygen levels are monitored by the software. However, automatic ammonia concentration and moisture regulation in casing soil still seem to be uncommon. Dutch mushrooms were the first to use climate computer farming more than two decades ago, and they are now widely employed in the sector [34]. Climate control in industrial facilities enables monitoring and administration of numerous mushroom growth rooms with a little touch. A computerized environmental control method allows farmers to monitor and change the plant variables' ambient conditions electronically [35]. Placement, size, choices, and plucking of mushrooms are all part of the harvesting process. Compression investigations with cylindrical mushroom sample parts yielded the mechanical characteristics needed for automated harvesting analysis [36, 37], spawning generation is a barrier to mushroom growth because creating high-quality spawn demands a permanent facility, specific skills, and an autoclave, a sort of high-pressure cooker, expansion in low-resource locations is difficult, the facilities commonly seen in research labs and universities [38]. Producers in low-income countries must choose between producing their own spawn and purchasing it fully prepared. Producing spawn takes at least one year of competence as well as the capacity to maintain a sterile environment, which may be costly and energy-consuming. If growers are unable to produce viable spawn, most of the mushroom growth process will be halted. Because they lack the means to spawn high-yielding quality cultures, mushroom enterprises in low- and middle-income countries obtain seeds regularly from other developed countries like United State and Europe. Because locally produced cultures do not have high biological efficiency, the majority of commercial mushroom cultivation in Latin America is currently done with imported spawn. As a result, fruiting yields are less than half of those of foreign spawns [39]. Outdoor cultivation takes place periodically beneath the forest canopy, with mushroom beds built on a high platform made from bricks and bamboo poles. Hand or motorized cutters are used to cut the top leafy piece and a section of the sturdy stalk towards the roots to make straw bundles 45 cm long and 10 cm wide. After arranging the bundles side by side, the mushroom spawn is put in six to eight regions and coated with red gram dal powder. The spawn cycle needs at least 39 degrees Celsius and will take 6–7 days to complete. The mushrooms start to emerge after 12–13 days of spawning [40]. Internal gardening may be completed using a substrate/compost composed of cotton ginning mill refuse and paddy straw. Steam is brought into the cropping chamber in order to heat condition the compost. For 4–5 hours, the temperature is kept at 62 degrees Celsius. The plastic sheet will be used to cover the mattresses. During the spawn run,

the room temperature is kept at 32–34 degrees Celsius. Within up to five days, the compost colonizes, and the beds are watered once the plastic covering is removed. The pinhead appears on the fifth-sixth day of spawning. The initial flush of mushrooms is available for picking after another 4–5 days. The paddy straw mushroom should not be refrigerated and should be used shortly after collecting or for a few hours, it was maintained at cellar temperature [40].

3. Challenges in mushroom cultivation

The mushroom industry’s development is hampered by a number of concerns and obstacles across the globe. The mushroom business is gradually establishing itself in many emerging regions, but progress is slow due to a lack of scientific study and dialog. Mushroom farming might possibly play a role in long-term agriculture and forestry [41]. Several difficulties and obstacles that might hinder effective mushroom cultivation among small-scale farmers have been highlighted, necessitating attention and ways to boost mushroom productivity and market access [42]. Personal efforts are necessary to face adversity such as a shortage of substrate, community commitments, and the creation of ideal mushroom homes, while government intervention is required for others (Table 1).

Challenge	Action required
Absence of up-to-date technologies	Based on local demands and agro-climatic circumstances, develop or acquire relevant technologies.
Inadequate funding and scientific investigation into mushrooms.	Invest more money
Deficiency of a suitable substrate	Look to expand the raw material and consider other options depending on what’s easily obtainable.
Spawn of low quality	Construct a mushroom cultivation center, as well as spawn production facilities that are technologically advanced. Ensure a steady supply of high-quality spawn at a minimal expense.
Pest assault and poor agricultural management systems	Enhancing producers’ experience and abilities in the areas of agricultural hygiene and integrated pest and diseases control.
Inadequate harvesting management	Enhancing skills and experience in the fields of selecting, assessing, and preservation, refrigerated storage, refrigerated transportation, adequate treatment, packaging design, and labeling at the appropriate stage.
Extreme environmental conditions	When the temperature is high, moisten the mushroom house’s floor, roof, and walls often.
There aren’t enough mushroom policies and rules in place.	Create and aggressively implement mushroom-related regulations and legislation. Increasing fresh investment in order to become more competitive. Establish special rules for mushroom commodities in terms of trade, marketing, and food safety.
Mushrooms fall short of market expectations.	Gather the mushroom in a reasonable timeframe to get a decent market price.

Table 1. Challenges and action required in mushrooms cultivation [41, 42].

4. Global mushroom cultivation prospects

These Mushrooms have long been used in traditional medicine in China, Africa, the Middle East, and Japan particular. Edible mushrooms could only be found in nature and were hard to farm and sustain Wild forest collection is still popular across the world, especially in southern Asia [43, 44] and in developing nations [45]. Auricularia, Flammulina, and Lentinula are examples of mushrooms. Have been most probably initially farmed in China and other Emerging nations around the year 600–800 AD [46]. Pure mushroom cultures were first created from spores and tissue towards the turn of the twentieth century when they were first grown on a wide scale. The quantity of wild mushrooms is decreasing as a result of both degraded surroundings and natural resources, as well as more expensive labor, produced mushrooms provide more food items which decrease food insecurities, they also provide more affordable and healthier meals [47]. With the global population expanding and acreage per capita shrinking, fast industrial development, global warming, and a desire for excellent and functional foods, secondary agriculture and novel crops like mushrooms will be necessary. Mushroom farming might potentially play a significant role in sustainable agriculture and forestry. Agriculture, forestry, and food processing create massive amounts of a diverse range of organic waste. The mushroom industry has a major and extensive influence on livelihoods and reducing poverty. There have been hundreds of discovered fungus species that have made major contributions to human diet and medicine. Mushroom Young mushroom mycelium hypha total amount **Figure 1:** The basic mushroom life cycle 4 According to S. Gupta et al., there are now 110,000 species of fungus [48], 16,000 (15%) of which are mushrooms [48, 49]. There are around 3000 types of edible mushrooms from 231 genera [14, 49, 50], with only approximately 200 experimentally grown, In various countries, 100 are economically farmed, 60 are commercially cultivated, and more than ten are

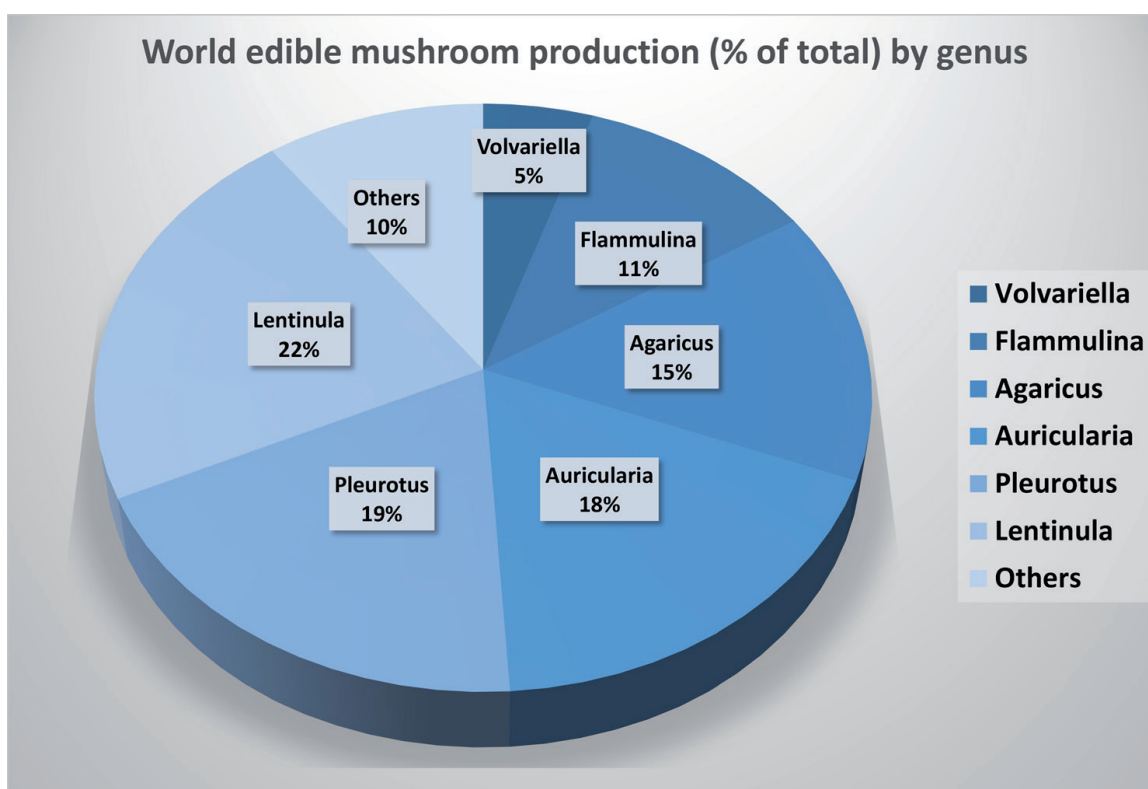


Figure 1.
Worldwide mushroom production.

produced industrially. Around 700 of the known 16,000 mushroom species are regarded harmless and have medicinal properties [49]. The inclusion of fresh varieties of mushroom farming for commercial purposes has resulted in a fast expansion of the worldwide mushroom business during the last two decades. Furthermore, mushroom cultivation and development have had a favorable influence in terms of economic growth worldwide, the influence of mushroom farming, mushroom derivatives, and mushroom foodstuffs on human well-being in the twenty-first decade may be termed as a “nongreen revolution.”

5. Nutritional value

Mushrooms are frequently high in protein and necessary amino acids, but low in fat [7]. Furthermore, these fungi have a substantial quantity of carbs and fiber, as well as vitamins (such as thiamin, riboflavin, cobalamin, vitamin C and D) and minerals (Se, Cu, Mg, Na, K, P, Fe, Ca, and Mn) [7]. The edible mushrooms had moisture percentage (81.8–94.8%), which depends on the mushroom species and other parameters like harvesting, growing, preparing, and storing conditions (Figure 2) [5, 6].

Crude protein contents in edible mushrooms *L. edodes* had a dry weight (DW) of 15.2 g/100 g, while *A* had a DW of 80.93 g/100 g. [6, 8]. They are high in glutamate, arginine, and aspartic acid, but low in methionine and cysteine, according to the FAO/WHO [6]. The limiting amino acids in *L. edodes*, *P. ostreatus*, and *P. eryngii* are leucine and lysine. Surprisingly, two new amino acids have been discovered: GABA (aminobutyric acid) and ornithine have been shown to have important physiological functions [6]. As a result, the nutritional significance of mushrooms is expected to grow in the next years as a result of the world’s rising protein need and a desire to avoid the risks connected with the usage of animal foods sources. Mushrooms that are edible have a low-fat content. Unsaturated fatty acids, notably palmitic acid (C16:0), oleic

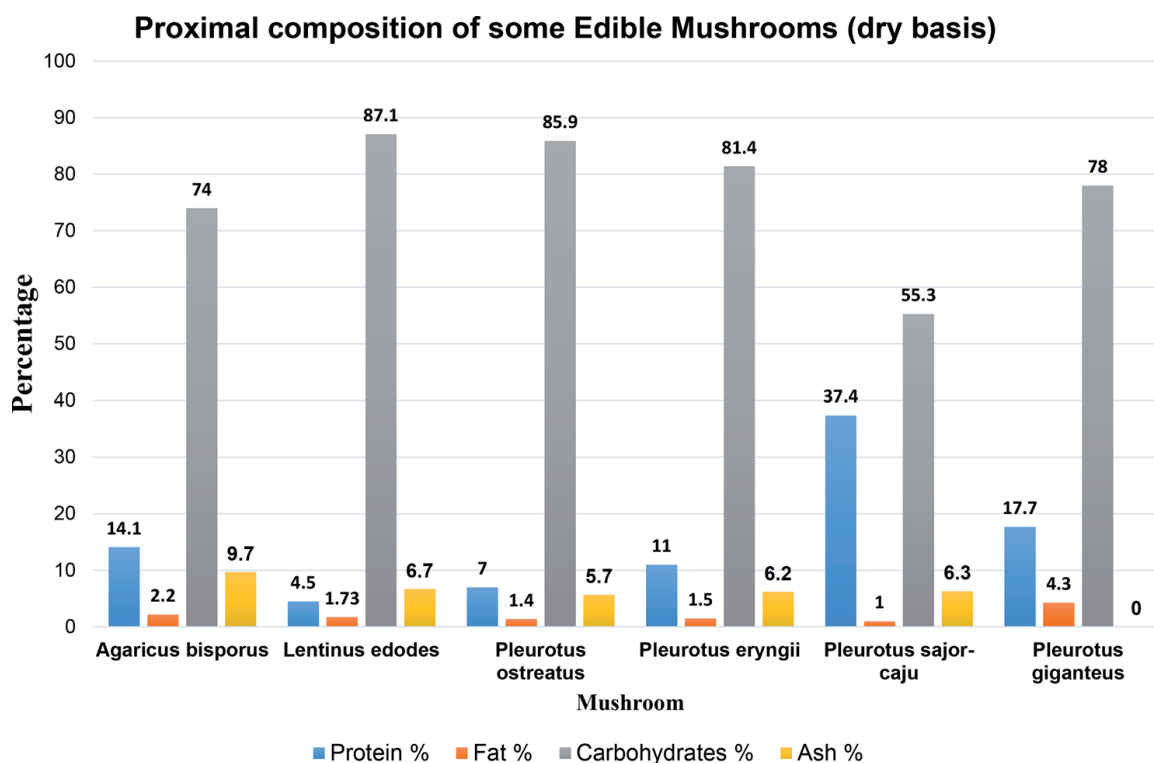


Figure 2. Nutritional content of some edible mushroom.

acid (C18:1), and linoleic acid, prevail over saturated fatty acids in general (C18:2) [51–53]. While the other FA was only found in trace levels, with the exception of *Lactarius deliciosus*, which possesses a high concentration of stearic acid (C18:0) [51].

6. Phenolic compounds

Phenolic compounds are aromatic hydroxylated compounds that include one or even more aromatic rings and hydroxyl groups. Many mushrooms have anti-inflammatory characteristics due to the prevalence of phenolic substances examples include flavonoids, hydroxycinnamic acids, oxidized polyphenols, lignans, phenolic acids, Stilbenes, hydroxybenzoic acids, and tannins (**Table 2**).

[70, 71]. These chemicals have been observed to behave as peroxide decomposers, antioxidants, and metal inactivators [72]. One of the most significant classes of secondary metabolites identified in fungal fruiting bodies is phenolic chemicals, and they have been shown to have antioxidative and anti-inflammatory properties [73]. *Imleria badia* was the initial examined organisms, with phenolic chemicals discovered

Edible Mushroom	Bioactive Compounds	References
<i>Agaricus campestris</i>	Vitamin C, D, B12, folates, and polyphenols	[54]
<i>Agaricus bisporus</i>	Fibers, Oligopeptide	[55]
<i>Agaricus brasiliensis</i>	Polyphenols and flavonoids, Oligopeptide	[56]
<i>Boletus bicolor</i> , <i>Leucopaxillus tricolor</i> <i>G. lucidum</i> , <i>Tricholoma giganteum</i> <i>Tricholoma matsutake</i> , <i>Tuber micheli</i> , <i>Hypsizygus marmoreus</i> , <i>Grifola frondosa</i>	Oligopeptide	[57–60]
<i>Catathelasma ventricosum</i>	Heteropolysaccharide	[57]
<i>Lactarius deterrimus</i>	Polyphenols and flavonoids	[61]
<i>Catathelasma ventricosum</i>	Heteropolysaccharide	[62]
<i>Lentinula edodes</i>	Lentinan KS-2	[63]
<i>Hericium erinaceus</i>	Flavonoids	[64]
<i>Lentinus lepideus</i>	Lentinan KS-2, flavonoids	[65]
<i>Pholiota nameko</i> SW-02	Mycelia zinc polysaccharide	[66]
<i>Pleurotus djamor</i>	Mycelium zinc polysaccharides	[67]
<i>Heterobasidion linzhiense</i> , <i>Ganoderma australe</i> , <i>Collybia peronata</i> , <i>Ganoderma lingzhi</i> , <i>Inonotus andersonii</i> , <i>Heterobasidion linzhiense</i> , <i>Inocybe</i> sp. <i>Phellinus gilvus</i> , <i>Lactarius hatsudake</i> , <i>Phellinus conchatus</i> , <i>Phellinus gilvus</i> , <i>Betulina Lenzites</i> , <i>Panellus</i> sp., <i>Phlebia tremellosa</i> , <i>Trametes versicolor</i> , <i>Phellinus gilvus</i> , <i>Phellinus gilvus</i> , <i>Phellinus gilvus</i> , <i>Ph stiptica postia</i> , <i>Tricholoma caligatum</i> , and <i>Rigidoporus</i> sp.	Polyphenol	[68]
<i>Hericium erinaceus</i>	Exo-polymer	[69]

Table 2.
Edible mushroom and some bioactive substance.

in the fruiting bodies, procatechuic, cinnamic, p-hydroxybenzoic, and p-coumaric acids, in particular. The phenolic content in total was 48.3 mg/kg dry weight. Additionally, the phenolic compounds of *I. badia* have unusually great antioxidant activity, reaching 99.2% in linoleic acid oxidation assays [74]. The cultivated species *A. bisporus*, on the other hand, includes gallic, caffeic, ferulic, p-coumaric, and procatechuic phenolic acids [75].

7. The therapeutic effect of mushrooms

The hunt for medical compounds derived from fungus has piqued the public's curiosity. Higher basidiomycetes have been shown to contain bioactive compounds with anticancer, immunomodulatory, anti-inflammatory, hypoglycemic, antiatherogenic, antimutagenic, and other health-promoting properties [76]. Mushrooms may reduce the risk of disorders including Parkinson's, Alzheimer's, hypertension, stroke, and cancer, as well as work as an antimicrobial, immune system booster, and cholesterol-lowering agent [77]. Mushrooms include other metabolites (terpenoids, acids, sesquiterpenes, polyphenols, lactones, sterols, alkaloids, nucleotide analogs, metal chelating agents, and vitamins), as well as polysaccharides and glycoprotein, particularly β -glucans. Additional proteins having bioactivity have also been found, including lectins, lignocellulose-degrading enzymes, protease inhibitors and proteases, hydrophobins, and ribosome-inactivating proteins, which can be used in biotechnological procedures to create new drugs [78]. Biologically active polysaccharides and protein complexes produced from mushrooms have anticancer effects both in animals and humans. Several of these mushroom polymers have been demonstrated to have immunotherapeutic effects by inhibiting and killing tumor cells in the past. Several mushroom polysaccharide components have been clinically studied and are widely and efficiently used to treat cancer and other illnesses in Asia. Certain mushrooms are estimated to generate a total of 126 therapeutic activities [79]. Anticancer polysaccharides generated from mushrooms are either acidic or neutral, have a powerful anticancer effect, and have a wide range of chemical structures. Antitumor activity has been identified in a broad variety of glycans, ranging from homopolymers to extremely complex heteropolymers. Mushroom polysaccharides have anticancer effect through stimulating the immune system of the host body; in other words, mushroom polysaccharides do not directly destroy cancer cells. Several substances help to reduce stress in the organism's systems and may result in a 50% reduction in tumor progression as well as a 50% improvement in tumor-bearing organism survival time [80, 81]. Glucans are the most often detected polysaccharides in mushrooms, accounting for about half of the fungal cell wall. Many edible mushrooms contain glucans, which are responsible for their anticancer, immunomodulatory, anticholesterolemic, anti-oxidant, and neuroprotective characteristics. They are also known as effective immune stimulators in humans, and their ability to treat a variety of disorders has been established. These biological reactions are induced when glucans bind to a membrane receptor.

Indole compounds are another class that has been shown to have radical scavenging and anti-inflammatory substance designated in mushrooms [82, 83]. These chemicals have a particularly powerful impact on animal immunological and neurological systems. Indole compounds identified in mushrooms comprise psychoactive compounds such as psilocybin and also non-hallucinogenic compounds

such as 5-hydroxy-L-tryptophan, L-tryptophan, serotonin, or tryptamine [82, 83]. Mushrooms have a great capacity to digest elements from the soil, making them a useful source of these compounds. Mushrooms collect bio elements with free radical scavenger and anti-inflammatory properties such as zinc, copper, iron, and selenium [84].

8. Mushroom and chronic diseases

The therapeutic qualities of mushrooms, as well as the existence of bioactive substances, are their most notable characteristics. Mushrooms' pharmacological qualities include immune boosting, homeostasis maintenance, biorhythm modulation, and, most critically, the treatment and prevention of a wide range of life-threatening diseases such as uncontrolled cell division, cerebral disorders, and cardiovascular disease. Mushrooms offer, antifungal, antioxidant, immunomodulatory, anti-angiogenic, anticarcinogenic, antiviral, antibacterial, hepatoprotective, hypoglycemia, antidiabetic, anti-inflammatory and other therapeutic properties [85]. Some mushroom polysaccharides or complexes with protein to form polysaccharides-protein which can enhance the host's defense system, it enhances non-specific immune response, and anticancer action [86]. Mushrooms are high in natural antibiotics. The molecule responsible for the antimicrobial action has been identified as oxalic acid. Eating *Tricholoma populinum* resulted in the resolution of severe allergy symptoms in two patients, one with thromboangiitis obliterans and the other with urticarial [87].

8.1 Impact of mushroom on cardiovascular diseases

Cardiovascular disease is one of the leading causes of death in both the developed and the developing world [88]. Food has been found to notably modify etiological risk factors associated with blood pressure alterations, homocysteine metabolism, hemostasis, lipid and lipoprotein digestion, and oxidative damage [89]. Triacylglycerol, blood pressure, homocysteine, LDL, and HDL cholesterol are all well-established measurements and commonly recognized markers. Only LDL and blood pressure, however, are considered diet-related indicators [89]. The hypocholesterolemic characteristics of edible mushrooms have long been employed in medicine [90]. Consuming edible mushrooms, in general, reduces the risk of heart disease attributed to the prevalence of certain compounds and other bioactive molecules. **Figure 3** depicts the processes of cholesterol metabolism involved in the hypocholesterolemic action of edible mushrooms.

The FA content of edible mushrooms proves to help in lowering blood cholesterol [51, 91]. When the Fatty acid proximate analysis of many edible mushrooms was studied, significant amounts of PUFA were identified. The presence of Tran's isomers of unsaturated fatty acids has the greatest impact on raising the blood cholesterol to high-density lipoprotein ratio, which raises the risk of cardiovascular disease [91–93]. Mushrooms did not contain Tran's isomers of unsaturated fatty acids [51]. Dietary fiber ingestion may have an effect on plasma lipid levels and lower the risk of heart problems [94]. Soluble dietary fiber has been demonstrated to have effects on serum lipid, decreasing total cholesterol and LDL [95]. Their vicious qualities are connected to an increase in bile acid and Short-chain FA excretion inhibits acetate uptake into serum lipids [9, 96]. *Auricularia auricula* and *Tremella fuciformis* are two mushrooms

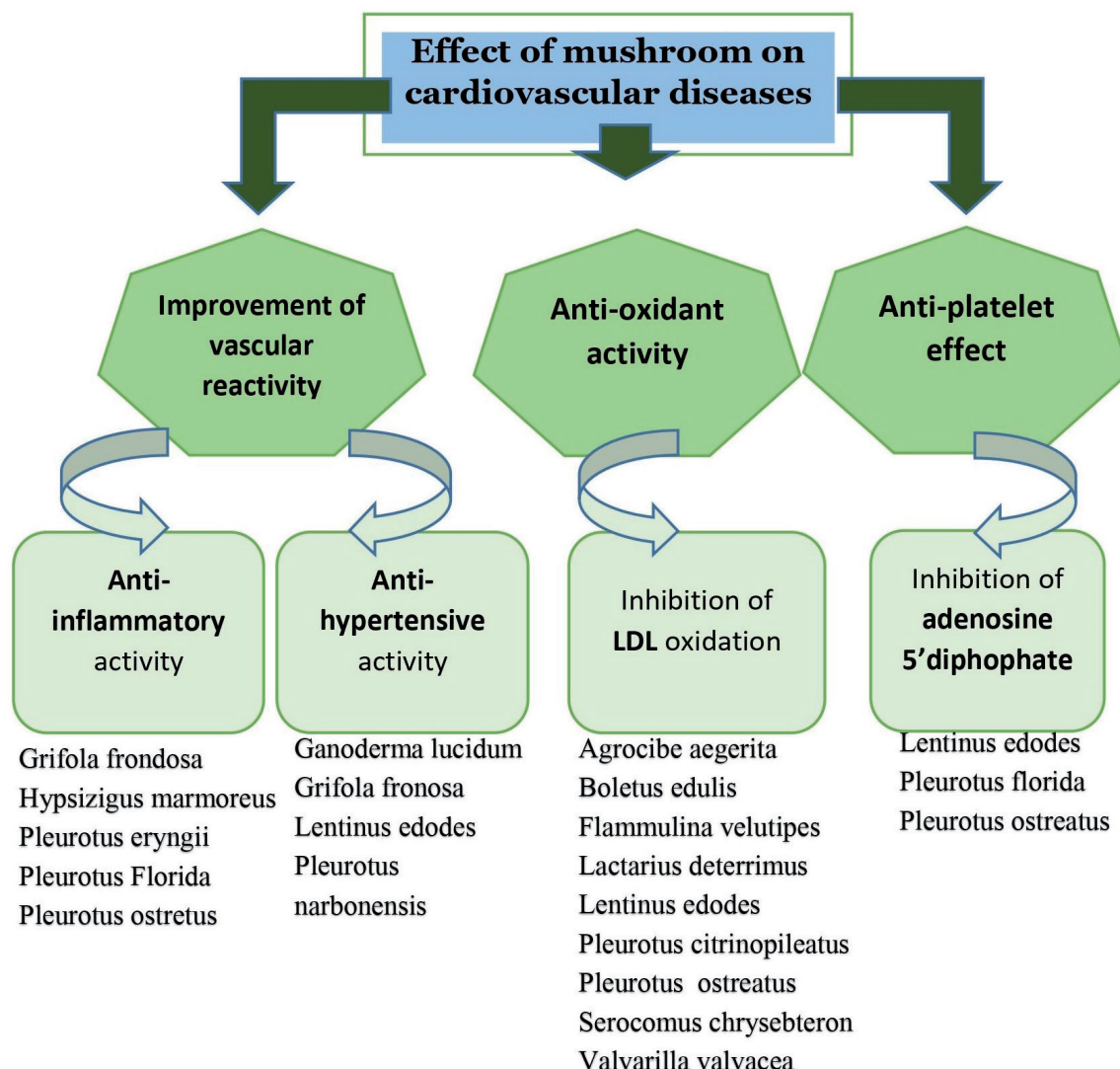


Figure 3.
Cholesterol metabolism and edible mushrooms.

with significant dietary fiber, that have been shown to reduce LDL levels and total cholesterol [97]. Mushrooms are especially interesting because they contain a high concentration of β -glucan polysaccharides, which have hypocholesterolemic and anticoagulant properties (Table 3) [106, 107].

Some fungal species have been shown to have anti-inflammatory effects [108], and edible mushrooms have been used to obtain natural anti-inflammatory chemicals. *P. florida*'s anti-inflammatory action has been indicated as a possible therapeutic application against cardiovascular illnesses [108]. Help to prevent cardiovascular disease, and there is evidence that proves that oxidative alteration of LDL (lipids or protein components) contributes to atherogenesis [109]. Mushrooms include a variety of antioxidant chemicals, including polysaccharides, nicotinic acid, triterpenes, ergosterol, and polyphenols [98]. Two extracts of *P. citrinopileatus* were shown to exhibit strong antioxidant activity, which may be related to antihyperlipidemic effects [110]. Oyster mushrooms decreased the frequency and size of lesions of atherosclerotic in coronary arteries [108]. High blood pressure. In terms of blood pressure effects, the mushroom's low salt concentration and high potassium content (182–395 mg/100 g) encourage its inclusion in the meal plan. In fact, from fruits and vegetable potassium has been shown to reduce blood pressure [6]. Several research

Edible mushroom	Hypocholesterolemia properties	References
Agaricus bisporus	↓Triglycerides in liver. ↓Serum total cholesterol. ↓Adipocytokine. ↓LDL. ↑Hepatic LDL receptor mRNA. ↓The fat deposition.	[98, 99]
Auricularia auricular Lentinus edodes	↓LDL. ↓cholesterol levels. ↓phospholipids of plasma. Modification of hepatic phospholipids metabolism.	[100]
Pleurotus citrinopileus	↓Triglycerides in liver and blood. ↓Total lipids. ↑Bile acid excretion. ↓Total cholesterol. Inhibition of HMG-CoA reductase.	[101]
Pleurotus florida	↓Total lipids. ↓Total cholesterol. ↑Bile acid excretion. ↓Triglycerides in liver and blood. Inhibition of HMG-CoA reductase.	[102]
Pleurotus ostreatus	↓Plasma triglycerides, maintain normal Blood pressure ↓VLDL. ↓LDL. ↓Total cholesterol. Inhibition of HMG-CoA reductase.	[103, 104]
Tremella fuciformis	↓LDL. ↓Plasma triglycerides. ↓Total cholesterol. ↓Hepatic total cholesterol.	[105]

Table 3.
Edible mushrooms with hypocholesterolemia properties.

has been conducted to study the antihypertensive activity of edible mushroom species such as *Ganoderma lucidum*, *pleurotus narbonensis*, *G. frondosa*, and *L. edodes* (**Figure 4**).

The potassium, vitamin C, and fiber found in mushrooms help to improve cardiovascular health. Potassium, like salt, aids in blood pressure regulation. Consuming shiitake can help reduce the risk of health problems and coronary heart disease since they are high in nutrients and low in salt. Mushrooms are especially interesting since they contain a lot of β -glucan polysaccharides, which have anticoagulant and hypocholesterolemic properties [107]. Chitin (N-acetyl-D-glucosamine polymer) or Chitosan (D-glucosamine polymer) are two more fascinating fungal polysaccharides that have comparable properties to dietary fiber and lower triglyceride levels in the body [99]. Eritadenine, also known as lentinacin (or lentysine), is a purine alkaloid or an adenosine analog with hypocholesterolemic properties [109].

The angiotensin-converting enzyme (ACE) regulates the renin-angiotensin-aldosterone system's (RAAS) action and lowers blood pressure, which is inhibited by the majority of mushroom bio-components [110]. Polysaccharides and Triterpenoids, such as ganoderic alcohols, ganoderic aldehydes (ganoderals), and ganoderic acids are bioactive in *Ganoderma* (ganoderol). Ansor and colleagues recently reported that ACE

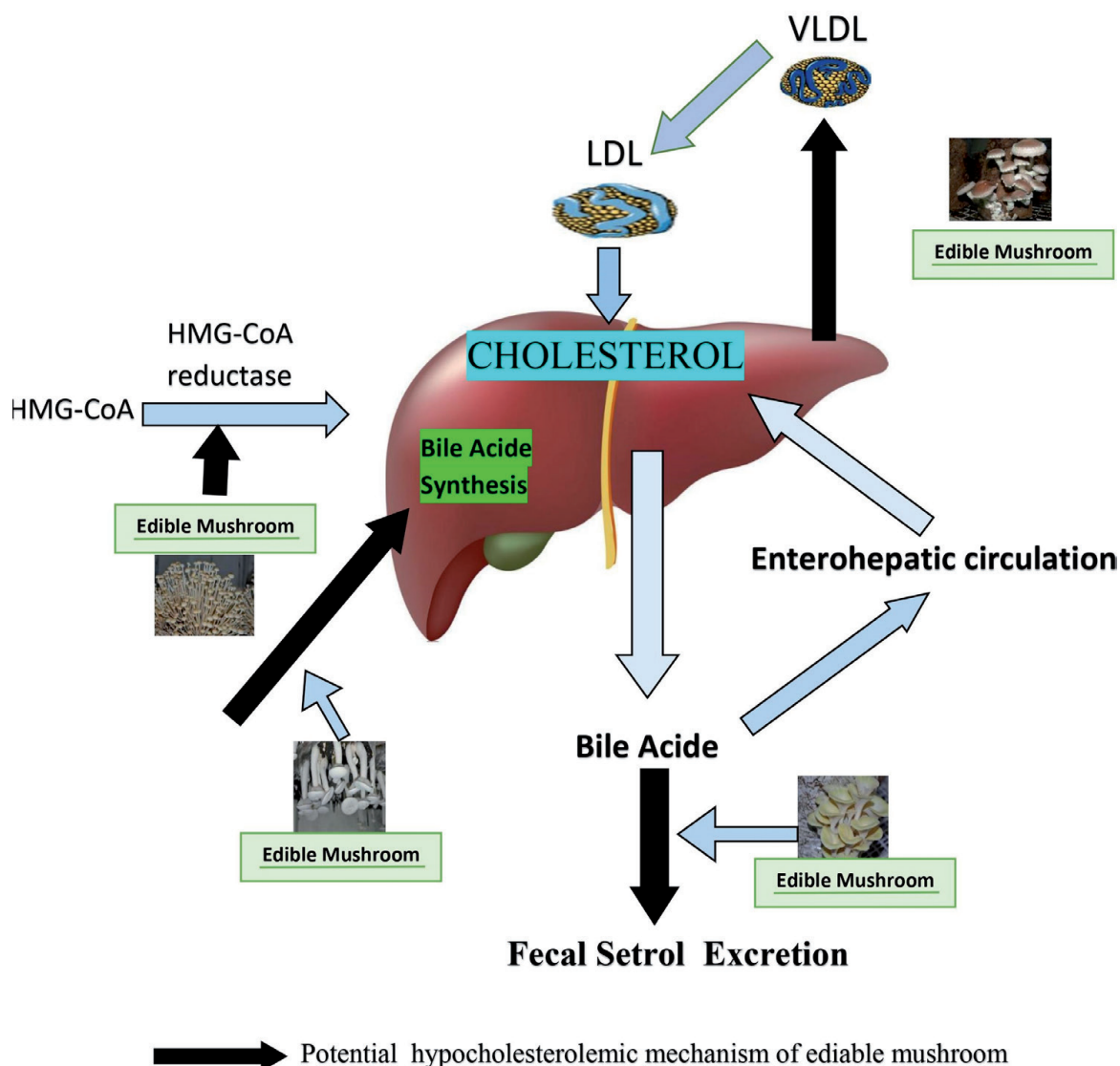


Figure 4.
Effect of edible mushrooms on cholesterol metabolism.

inhibitory peptides from *Ganoderma lucidum* can help to reduce blood pressure [111]. 3,3,5,5-tetramethyl 4-piperidone (TMP) from *Marasmius androsaceus*, l-pipecolic acid from *Sarcodon spratus*, d-mannitol from *Pleurotus cornucopiae*, Lentinan, chitin, and K⁺ from *Lentinula edodes*, are all anti-hypertensive mushroom bioactive elements [110].

8.2 Edible mushrooms and obesity

Since time immemorial, mushrooms have been widely utilized as meals, nutraceuticals, and medications [112]. Mushrooms have low energy properties in it, which is very crucial in weight loss. Mushrooms also contain a high vitamin-D and B-complex content, as well as high mineral content and a considerable amount of numerous trace elements, including selenium, which is a strong antioxidant [113]. Aside from their nutritional importance, mushrooms have unique qualities in terms of taste color, flavor, texture, and odor that are more fascinating for mankind's utilization. Many studies have advised that particular mushrooms be consumed on a regular basis, in food, or as an extracted substance. Some of these polysaccharides have antimicrobial and anti-inflammatory properties [114]. The beneficial benefits

of mushroom and polysaccharides on the gut microbiome, which has been related to diabetes and obesity, are currently being studied in a vibrant niche research field [115]. Because mushrooms have a high concentration of bioactive chemicals, they help to reduce obesity [63]. Numerous research has been carried out to study the polysaccharides produced from different mushrooms that have anti-obesity effects. Polysaccharides derived from *Coriolus Versicolor* stimulated splenocytes in mice via the MAPK-NF-B signaling pathway, resulting in an immunomodulatory result [116]. A polysaccharide from *Tremella fuciformis* decreased 3 T3-L1 adipocyte variation by reducing mRNA expression, indicating the carbohydrate's potential usefulness as an anti-obesity prebiotic [54]. *G. lucidum* consumption decreased adipogenic transcription factor expression, which enhances glucose and lipid transport and storage, and enables AMPK signaling pathways, demonstrating the polysaccharide's potential as an anti-obesity and antidiabetic drug [117]. Eating white mushroom (*Agaricus bisporus*) may have anti-diabetic and anti-obesity properties. Similarly, this research has been broadened to include more mushroom species that are extremely useful such as *Lentinus edodes* (shiitake) and *Heridium erinaceus* (Lion's mane) [118, 119].

8.3 Effect of mushroom on cancer

The cell cycle was arrested at the G0/G1 phase, according to flow cytometry data. Methanol extract inhibited cell proliferation and growth in breast cancer patients by upregulating p21, p19, p53, and p27 genes and downregulating E2f transcription factor 1, PCNA, CDK4, CDK6, and Transcription factor DP-1 expression. Polysaccharides from *Pleurotus ostreatus* suppressed angiogenesis in MCF-7 cells by downregulating VEGF factor expression. Polysaccharides also increased the production of caspase-3, Bax, caspase-9, and phospho-JNK, as well as reducing mitochondrial membrane potential, resulting in cell death [120]. Supplementing rats with glucan produced from oyster mushrooms with breast cancer was associated with a decrease in tumor recurrence, tumor volume, and total tumor nodules [121].

Figure 5 shows a possible molecular signaling cascade implicated in *Pleurotus* species' anti-cancerous activity:

- a. *Pleurotus* extract inhibits Cox-2-PGE2 pathway, which stimulates angiogenesis, and the VEGF (potent angiogenic factor) route, which is necessary for tumor development.
- b. The bioactive chemicals found in N-cadherin decreased cell transformation. MMP-2 and MMP-9 (Zn-dependent endoproteases) are inhibited by mushroom extract, which is essential for EMT (Epithelial Mesenchymal Transition) in cancerous cells through tumor formation.
- c. Mushroom extract inhibits anti-apoptotic protein (Bcl-2) while activating/upregulating pro-apoptotic components such as bid, bax, cytochrome c release, fas, and cellular damage occurs.
- d. It prevents cells from progressing through the cell cycle and suppresses malignant cell growth via a p53-dependent and p53-independent route.
- e. In several types of malignant cells, its bioactive chemical causes DNA fragmentation.

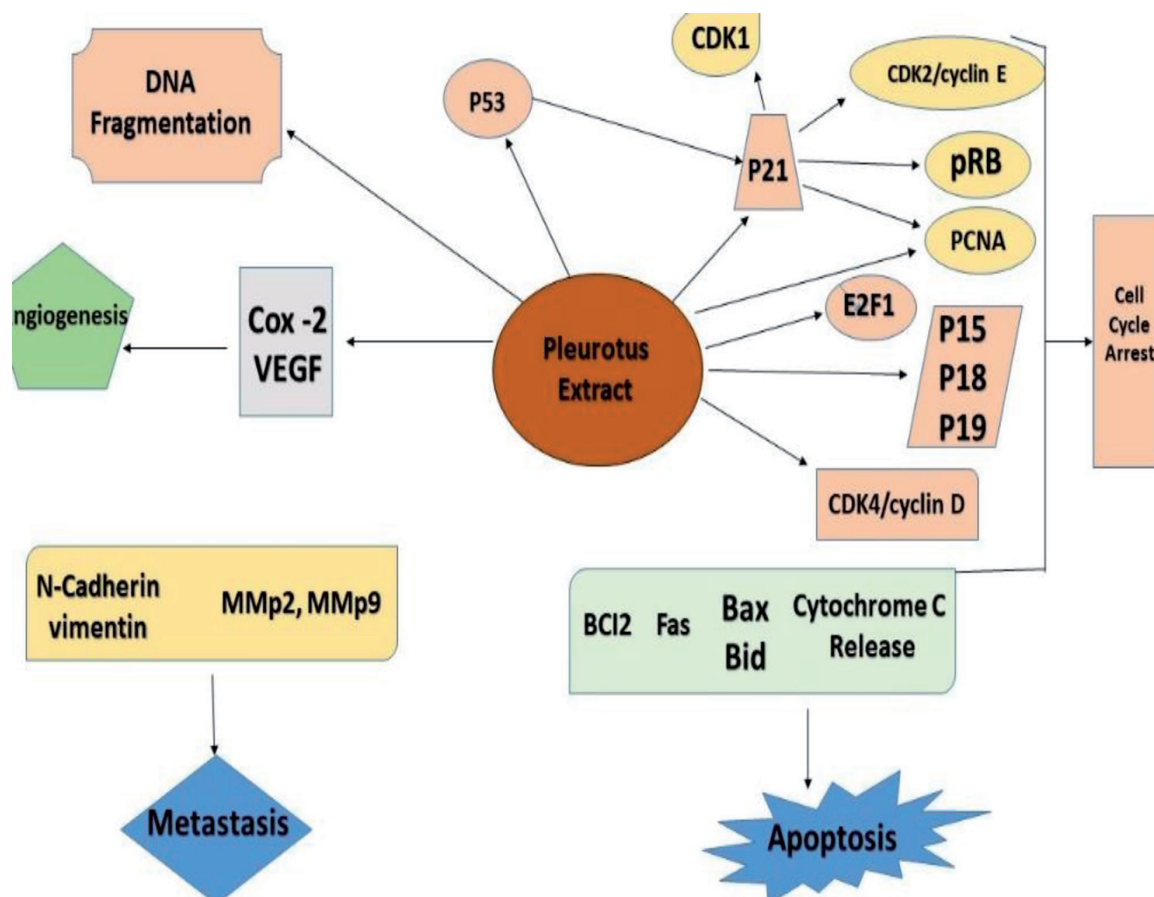


Figure 5. *Pleurotus extracts induced the activation and modulation of several signaling pathways in cancer cells, resulting in the prevention of cancer cell development, procreation, angiogenesis, and metastasis, as well as cell death.*

After 72 hours of exposure, because of its potential to elicit humoral and cellular immune responses against cancer cells, HeLa cells were suppressed by 60% by *Pleurotus sajor-caju* extracellular polysaccharide which is a sulfated derivative and HPV16E7 vaccines derived from β -glucan produce from the same species can be used for cervical cancer therapy [122, 123]. The anti-proliferative impact of gold nanoparticles generated by photo-irradiation from *Pleurotus Florida* was dose-dependent against human chronic myelogenous leukemia cell lines K-562 [124]. Immunomodulation is a method that uses immune cell activation can aid in the targeting and destruction of tumor cells while also imbuing the encounter with long-term memory. The activities include lymphoid cell stimulation, cellular immune function enhancement phagocytosis stimulation [125, 126].

Colorectal cancer cell development is inhibited by methanolic extracts of *Ganoderma* dried fruiting bodies induce by cell growth in the G2–M cell cycle phase, which is caused by cell proliferation. Methanol extract promotes p 21 and p 27 while downregulating cyclin A and B kinase proteins [127]. *Pleurotus ostreatus*, an edible fungus, has antiapoptotic action due to the presence of β -glucan, a therapeutic carbohydrate with a low molecular weight. Lectin derived from the extract of the therapeutic fungus *Clitocybe bularis* has anti-proliferative action against human leukemic T cells. Most lectins have several carbohydrate-binding sites, which attach to a glycosylated cellular receptor of T cells, triggering the antileukemic signaling cascade [128]. The impact of triterpenes derived from *Ganoderma lucidum* mycelial extract on human leukemia cancer cell lines HT-29 exhibits cell cycle arrest in the G2–M phase [129]. Stomach cancer is caused by smoked meat, a high-salt diet, while

complex carbohydrate, fruits & vegetables, consumption of high dietary fiber, a low-fat diet, and dairy products lowers the incidence of gastric cancer [130]. *Ganoderma lucidum* is one of the most extensively used medicinal fungus species for combating stomach cancer [131].

8.4 Role of mushroom in diabetes

Hyperglycemia (abnormally high fasting and postprandial glucose levels in the blood) refers to a group of illnesses with various etiologies that are a serious public health concern globally. Mushrooms, which have historically been used as diabetic treatments, constitute an attractive topic for the development of novel forms of therapies for diabetes and its after-effects. Many mushrooms have been shown to manage blood glucose levels clinically and/or experimentally and to alter the course of diabetes problems without causing negative effects [41, 132]. Aside from improving hyperglycemia, β -glucan treatment in diabetes settings has been demonstrated to produce a systemic enhancement that may improve the body's resilience against the development of diabetic complications [133–135]. Mushroom-glucans are polysaccharides that do not include starch and have a core of glucose polymer chain with extra beta-(1–6) branch points. The length of the β -glucan main chains varies, as do the kinds and degree of complication of side-chain branching. High molecular weight glucans with more structural complexity are thought to outperform low molecular weight glucans in terms of efficacy. Mushrooms also include heteropolysaccharides D-glucans with xylose, mannose, galactose, and uronic acid chains, as well as glycoproteins D-glucanprotein complexes [136].

Mushrooms have a high fiber content of roughly 3 g. per cup, which can assist persons having type 1 diabetes control their blood glucose. Blood sugar levels, cholesterol, and insulin levels in patients with type 2 diabetes can all be improved. However, having diabetes is not a requirement for eating a high-fiber diet. According to usual eating standards, the female should eat 25 g of fiber per day while an adult man should take 38 g. In 100 g dried powder of *Pleurotus florida*, phytochemical screening revealed the presence of alkaloids 1.92 mg, flavonoids 2.78 mg, saponins 0.05 mg, phenols (61.85 mg catechol equivalent), tannins 0.52 mg, glycosides 0.12 mg, and terpenoids 0.08 mg, which show anti-diabetic characteristics by lowering blood glucose levels [128]. Mushrooms, particularly α -glucans and polysaccharides have the ability to improve the secretion of insulin by β -cells, improving pancreatic cellular functions, which reduces blood glucose levels. It has been demonstrated to increase insulin sensitivity in peripheral tissues [137]. In the pancreatic tissues of rats, lectins isolated from *Agaricus campestris* and *Agaricus bisporus* stimulated the release of the hormone insulin from islets of Langerhans [138].

8.5 Effect of mushroom on immune system

Immunomodulatory mushrooms are the most often employed medicinal mushrooms in today's Korea, China, Japan, and Asian nations. Some polysaccharides or polysaccharide-protein complexes from different types of edible mushrooms have been proven to enhance the non-specific immune system and perform anticancer action by activating the host's defensive system [86]. These medications cause effector cells such as T lymphocytes, macrophages, and NK cells to release antiproliferative cytokines such as IL-1 β , IFN-g, TNF-a, and others, which induce tumor cell death and differentiation [139]. β -glucans contained in edible mushrooms have been shown to have an immune-boosting impact [140]. Specific β -glucans receptors are preferentially

expressed on the surface of neutrophils, dendritic, natural killer (NK) cells, and monocyte/macrophages, when β -glucans are consumed [141], The activation of the nuclear factor κ -lightchain-enhancer of activated B cells (NF- κ B), generation of cytokines, transcription of inflammatory-immune genes, reactive oxygen species (ROS) and nitric oxide (NO) occurs after the receptor recognition stage (ROS) [142, 143]. Other pattern recognition receptors (PRR) have been linked to β -glucan recognition, and they may work in tandem with dectin-1/TLR or perhaps independently [144]. β -Glucan receptors may be inhibited after damage, but β -glucans from a fungal pathogen, which produce large quantities of the interleukin-1 receptor antagonist (IL-1RA), can activate a significant immunomodulatory response independent of these receptors [144]. One of the finest dietary sources of selenium is edible mushrooms [145]. Selenium is required for the immune system to operate properly. Selenoproteins are selenium-bound proteins that play a role in immune system cell differentiation, proliferation, and activation, regulating both the congenital and adaptive immunological responses. Selenium's immunoregulatory effect is further demonstrated by its impact on leukocyte activities such as migration, phagocytosis, adhesion, as well as cytokine release, which may be critical in chronic inflammation and autoimmune disorders. Furthermore, selenoproteins play important role in cellular antioxidative activities. Selenium is an important component in the fight against free radicals, thanks to its involvement in the architecture of Superoxide, or glutathione peroxidase, among other things.

Numerous mushroom species included ergosterol (vitamin D precursor) and ergocalciferol (vitamin D₂), as well as other sterols. Ergosterol is abundant in the fruiting bodies of *A. bisporus* [146]. Vitamin D has a wide range of benefits for humans, according to current studies. Its scarcity has been linked to the onset of metabolic syndrome and hypertension, as well as intestinal inflammation, diabetes, and other health problems and certain types of malignancies, all of which are caused by chronic inflammation [147].

8.6 Mushrooms' effect on bone health

Mushrooms include a variety of bioactive chemical ingredients that aid in bone metabolism and reduce the risk of osteoporosis in humans. Mushrooms increase the osteogenicity of cultured bone cells and induce bone formation and mineralization [148]. Edible Mushrooms are a rich source of vitamin D. Vitamin D's main function is to keep bones healthy by stimulating calcium absorption from the gut and maintaining calcium homeostasis. Vitamin D insufficiency is a worldwide problem that also affects regions with enough sunshine [149]. Vitamin D deficiency may exacerbate bone loss by lowering calcium absorption and raising parathyroid hormone levels [150]. Rheumatoid arthritis is a degenerative joint condition that causes impairment. Inflammation in joints resulted in the loss of form and function as people become older, about 35–45 years old. Women are more impacted than males when it comes to chronic inflammation, joint pain, and autoimmune illness, which is characterized by chronic inflammation, joint pain, and autoimmune disease. A poly-branched (1,3/1,6)- β -D-glucans from *P. Ostreatus* has been shown to have anti-arthritic action [151, 152].

8.7 Neurodegenerative diseases and mushroom

Neurodegenerative diseases (NDs) are a type of neurological disorder that causes the brain or nervous system to deteriorate over time. Alzheimer's disease (AD) is the most common neurodegenerative disease and the most common cause of dementia.

The two major mechanisms that contribute to its advancement are oxidative stress and neuroinflammation [153]. Edible mushrooms have high levels of polyphenols, polysaccharides, vitamins, carotenoids, and minerals, all of which have antioxidant and anti-inflammatory properties [154]. Recent research has shown that mushrooms can help with some elements of neurodegenerative illness; nevertheless, human studies are inadequate to prove clinically significant consequences on brain health indicators. Although, it has been discovered that mushroom eating slows the onset of Alzheimer's disease and protects against β -amyloid peptide toxicity in the brain and moderate intellectual disability [85]. Niacin-rich mushrooms have higher therapeutic effectiveness in the rehabilitation of Parkinson's disease [155]. Polyozellin, a bioactive substance found in edible mushrooms, might be used to test Huntington's disease sufferers [156]. Polysaccharides, hericenones and erinacines, Erinacine A, Psilocybin, Triterpenoids, nucleotides, sterols, steroids, Quercetin, β -D-glucan, Ergothioneine, Selenium, vitamin D2, antioxidants, glutathione, and ergothioneine are examples of bioactive components present in edible mushrooms that have a protective effect against neurodegenerative disease [157].

9. Conclusion

Mushrooms, without a doubt, maybe called functional food. According to current dietary recommendations for disease prevention and treatment, edible mushrooms have adequate nutritional content, and their consumption can impact several identified risk indicators. Mushroom consumption obviously has a cholesterol-lowering or hypocholesterolemia impact through many methods such as reducing VLDL, enhancing lipid metabolism, blocking HMG-CoA reductase activity, and so delaying the chances of cardiovascular diseases. Several studies have shown that eating mushrooms on a daily basis considerably decreases chronic diseases like cancer, atherosclerosis, diabetes mellitus inflammation, obesity, and many other diseases. However, this technique should be accompanied by frequent physical exercise, nutritional and lifestyle adjustments. Regular mushroom eating may result in synergistic and better results. Mushrooms' antioxidant and anti-inflammatory components also help to lessen the burden of many ailments.

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Conflict of interest

There is no conflict of interest.

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