Journal of Chemical Health Risks

www.jchr.org

JCHR (2024) 14(2), 1463-1484 | ISSN:2251-6727

Bioactive Compounds from Pleurotus Ostreatus: Unlocking Immunomodulatory, Antioxidant, Antimicrobial, And Anti-Tumor Activities

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(Received: 07 January 2024 Revised: 12 February 2024 Accepted: 06 March 2024)

KEYWORDS
Ultraviolet rays, Mushroom, Antiviral, Antibacterial, Antitumor, Bioactive, Sunlight.

ABSTRACT:
The present review paper examined the nutritional and therapeutic properties of mushrooms as well as their other uses. Throughout human history, mushrooms have played significant roles as food, medicine, legands, folklore, and religious objects. Lately, they have gained popularity as a healthy diet and as a source for medicine development. Numerous physiologically active substances found in many higher mushrooms have been shown to have potential effects on cardiovascular health, hepatoprotection, anticancer and immunomodulation, antiviral and antibacterial properties, hypocholesterolemia and antitumor activities. Because of its remarkable ligninolytic capabilities, the Pleurotus genus is one of the most researched white-rot fungus. In addition to being edible, this fungus offers a variety of biological benefits since it possesses significant amounts of bioactive compounds. Some mushroom species that are often consumed can produce quantities of vitamin D that are significant to nutrition when they are subjected to ultraviolet (UV) radiation, such as sunlight or UV lamps. This review shows that the available data about how UV light affects mushrooms' ability to store more vitamin D2 and we discuss the issues with the pharmacological applications of mushrooms and their bioactive compounds.

1. Introduction

Mushrooms, belonging to the kingdom Fungi, are a diverse and captivating group of macro-organisms that have garnered extensive attention across various fields of study. Their unique biology, ecological roles, nutritional value, and medicinal potential have made mushrooms a subject of considerable scientific investigation and cultural fascination [1]. Mushrooms are taxonomically diverse, with over 1500 documented species, and they can be classified into various orders, including Ascomycota and Basidiomycota within the subkingdom Dikarya. These diverse species exhibit a wide range of morphologies, from the familiar to the exotic, and are distributed across ecosystems worldwide [2]. Mushrooms have been played an important role in human activity for long time. For more than 3,000 years, people in the Eastern world have used mushrooms for a variety of common medical purposes and various nutrional purpose. Mushrooms are distinguished by their characteristic fruiting bodies, consisting of a stem (stipe) and a cap (pileus). These structures serve as the reproductive organs, producing spores for dispersal. Unlike plants, mushrooms lack chlorophyll, rendering them unable to photosynthesize. Instead, they obtain nutrients through the decomposition of organic matter, mycorrhizal symbioses, or parasitism [3]. Mushrooms contain ergosterol (provitamin D2), proteins, vitamins and carbohydrates. Among the subkingdom Dikarya, mushrooms are found in both the Ascomycota and Basidiomycota orders. A total of about 2650 species of mushrooms have been discovered worldwide, of which 650 are used medically and 2000 for food [4]. There are both unicellular and multicellular mushrooms, a type of fungus. Due to a lack of chlorophyll and cellulose, they are unable to produce their own food. As a result, they must rely on host plants or animals as parasites in order to survive. 'Mushroom' refers to a fungus visible to the human eye, a 'macro fungus'. A basidiocarp has a stipe and a cap, and is usually called the fruiting body. Spores germinate, become mycelium, and when mated with compatible hyphae form the primordia, which will become fruiting bodies. Fungal taxonomy is the scientific classification of fungi based on their evolutionary relationships and morphological characteristics. Fungi constitute a diverse group of organisms that play crucial roles in ecosystems as decomposers, symbionts, and pathogens. The taxonomy of fungi has undergone significant revisions in recent years, aided by advancements in molecular biology and DNA sequencing techniques. Traditionally classified into divisions such as Zygomycota, Ascomycota, and Basidiomycota, recent molecular studies have reshaped our understanding of fungal relationships. The use of DNA sequences, particularly from the ribosomal RNA region, has enabled more accurate phylogenetic placement of fungi. The International Code of Nomenclature for algae, fungi, and plants (ICNafp), which provides guidelines for naming and classifying fungi. As the field continues to evolve, ongoing research and collaborative efforts contribute to refining our knowledge of fungal diversity and relationships [5]. The medicinal properties of mushrooms have been recognized since ancient times. In 1991, a melting glacier in the Italian Alps contained a 3500-year-old mummy along with a mushroom, which was likely used to treat intestinal parasites. The medicinal, nutraceutical, nutritional, and psychoactive civilizations including Greece, Rome, China, and India. The practice of medicine in the East [6]. There is a chance that the secondary metabolites found in mushrooms could be used therapeutically [7]. Forests include a variety of tress, animals of various, aquatic biomes and microorganism and wild mushrooms, which have been valued for their superior therapeutic qualities since ancient times [8]. According to estimates, around 50% of the yearly harvest of 5 million metric tons of mushrooms include useful or medicinal characteristics that can be employed as a source of biologically and physiologically active compounds. Researchers have discovered that mushrooms may contain biological properties that include anti-bacterial, anti-fungal, anti-tumor, cardiovascular-tonic, cholesterol-lowering, antiviral, anti-inflammatory, anti-hepatotoxic, and immune-modulating action [9]. The two types of phenolic acids that can be found in mushrooms—derivatives of cinnamic and benzoic acids—are the most prevalent phenolics there are. In general, hydroxybenzoic acid concentrations in plants are modest, but hydroxycinnamic acid concentrations are more prevalent and mostly made up of p-coumaric, caffeic, ferulic, and sinapic acids [10]. Edible mushrooms, cultivated or sought from the wild, are widely savored in many countries. Their consumption has experienced notable growth owing to their delectable taste, ready availability, and their appeal as functional foods. These attributes are due to their low calorie, sodium, fat, and cholesterol content, alongside their high levels of protein, carbohydrates, dietary fiber, vitamins, and essential amino acids [11]. Moreover, their unique flavor and nutritional advantages have significantly contributed to enhancing human dietary health [12]. Mushrooms are recognized as a key ingredient in gourmet cuisine worldwide, prized for their exceptional flavor, and are regarded as a culinary marvel by humankind. Out of the more than 2,000 mushroom species found in nature, around 25% are commonly accepted for consumption, and only a limited number are actively cultivated for commercial purposes [13]. Several bioactive substances, including phenols, polysaccharides, terpenoids, steroids, proteins, nucleotides, and glycoprotein derivatives, are abundant in mushrooms. These bioactive components have led to the recent use of mushrooms as prebiotics and dietary supplements to improve consumer health. Among these bioactive elements, polysaccharides, which are prominently present in edible mushrooms, give them a wide range of biological capabilities. Some of these qualities are anti-inflammatory, antibacterial, anti-tumor, immune-regulating, anti-hyperlipidemic, antiviral, antioxidant, and liver-protective. These properties underscore the potential medicinal significance of mushrooms [14]. When free radicals (ROS & RNS) are present in cells at higher-than-normal concentrations, it is referred to as oxidative stress. When oxidative stress becomes excessive or occurs inappropriately, it results in harm to cells and tissues, particularly affecting components such as mitochondria, cell membranes, DNA, proteins, and lipids. The responsibility for neutralizing and protecting against these highly reactive free radicals falls upon primary antioxidants, which are a class of antioxidant enzymes [15]. Previous studies have reported that edible mushrooms can neutralize free radicals through their antioxidant activity—the presented review aimed to assess the various biological properties of edible mushrooms-Pleurotus ostreatus. Antiviral drugs work by blocking many several steps in the life cycle of a virus, including replication, protein synthesis, host cell factor interference, and receptor neutralization, to reduce the speed at which an infection spread. Vaccines and antiviral medicines are in short supply, making it difficult to combat newly emerging viruses. Finding an antiviral therapy that is both effective and safe for host cells is a major challenge. To avoid a 'one bug-one medicine' mentality, scientists have recently been searching for multi-target antiviral drugs. The demand for novel treatments is further exacerbated by the development of drug-resistant microorganisms and the emergence of previously incurable illnesses. It is possible to discover antiviral treatments from natural compounds and their derivatives. Bioactive molecules with as-yet-undiscovered chemical structures abound in these sources, suggesting they might be a source for new antiviral drugs. Natural products have long played an important part in the treatment of a wide variety of disorders throughout the world's traditional medical systems. Thirty percent to fifty percent of the global population uses traditional medicine to cure various illnesses. There are About 40% of all approved new medications in the United States are derived naturally or contain natural constituents. These bioactive substances may originate from bacteria, plants or animals [16]. Mushrooms shows that they have antimicrobial property due to the presence of chemicals that make up their fruiting bodies and have varied molecular weights. Alves et al. (2012) conducted a bibliographic investigation and found that most of the mushroom extracts they looked at had more antibacterial activity against gram-positive strains than gram-negative ones [17]. Mushrooms in particular might serve as a source of naturally occurring antibiotics, including low- and high-molecular-weight (LMW and HMW) antibiotics. molecules, respectively. LMW compounds include quinolines, steroids, anthraquinone and benzoic acid derivatives, sesquiterpenes and other terpenes, and quinolines. Primary metabolites like oxalic acid are also included. The majority of HMW substances are peptides and proteins. The number of species of mushrooms on earth is believed to be 1,40,000, but only 22,000 of them are known and only 5% of them have been examined. Therefore, there is a lot to learn about the characteristics and prospective applications of mushrooms [18]. Sunlight or an ultraviolet (UV) lamp can be used to produce sufficient vitamin D in certain edible mushroom species when exposed for an extended period of time. Mushrooms are rich in vitamin D2, with less quantities of vitamins D3 and D4, whereas animal foods are rich in vitamin D3. Some of the initial bone diseases linked to a lack of vitamin D is rickets, which has now been joined by others [19]. Rickets was a widespread disease in Europe and the United States in the early 19th century, especially in the region's northern industrial centres. In the late 19th century, autopsy examinations in Boston and Leiden, the Netherlands, indicated that 80-90% of children had rickets. Vitamin D insufficiency, calcium shortage, and acquired and hereditary abnormalities of vitamin D, calcium, and phosphorus metabolism can all lead to rickets. Development retardation, muscular weakness, skeletal abnormalities, stunted development, and bent legs are some of the specific symptoms. Some of the symptoms include short stature, muscular weakness, bone abnormalities, and bent legs [20][21]. Although the evidence for non-skeletal benefits is currently inconclusive [22], adequate vitamin D intake is crucial for the health of muscles and lowering the risk of elderly collapses [23]. It may also help to prevent certain cancers, respiratory disease in children, cardiovascular disease, neurodegenerative diseases, and both type 1 and type 2 diabetes [24][25]. Ergosterol is found in the cell membrane of fungi and only in a few selected species of algae, and when ultraviolet (UV) light on passed on ergosterol produces vitamin D2 (ergocalciferol), a synthetic version of vitamin D. The skin converts a cholesterol-like precursor called 7-dehydrocholesterol to vitamin D3 (cholecalciferol) by exposure to direct sunlight [20]. Vitamin D3 is vital for proper intestinal

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 1463-1484 | ISSN:2251-6727

calcium absorption. In the vitamin D series, vitamin D3 is an important but not the final active form. 7-dehydrocholesterol is converted by UV-B into pre-vitamin D3, which is subsequently isomerized into vitamin D3 by sunlight [26]. There is a common activation mechanism between vitamins D2 and D3. 25-hydroxyvitamin D [25(OH)D] is formed in the liver from vitamin D after it has been synthesised in the skin or obtained from food. 1,25-dihydroxyvitamin D [1,25(OH)2 D], commonly known as calcitriol, is a potent metabolite of vitamin D that is produced by the kidney and other organs.

2. Oyster Mushroom (Pleurotus genus)

Pleurotus, a member of the Pleurotaceae family, is distinguished by its coloration and typical habitat. These mushrooms are frequently cultivated as saprotrophic fungi and exhibit minimal parasitic tendencies. P. species, commonly known as "oyster mushrooms," are well-known around the world; Pleurotus ostreatus is one of the most widely grown species. Pleurotus genus is one of the most researched white-rot fungus. In addition to being edible, this fungus offers a variety of biological benefits since it possesses significant amounts of bioactive compounds [82]. Due to their well-established health benefits and biochemical characteristics, several edible mushrooms, such as white button mushrooms, different species, shiitake mushrooms, and numerous paddy straw mushrooms, are highly favored in cultivation [27]. Cultivating Pleurotus ostreatus offers numerous advantages over other edible mushrooms. This specific species, among the various species within its genus, stands out owing to its remarkable flavor, rich nutritional value, and therapeutic qualities [28]. A variety of bioactive compounds has been isolated and identified from the fruiting bodies of oyster mushrooms, making them a rich source of nutrients [29]. These bioactive compounds were responsible for various biological and pharmacological activities such as antioxidant, antibacterial, antiviral, anti-diabetic, anti-cancer, anti-hypercholesterolemic, and anti-immunomodulatory activity as shown in Figure 1 & 2.

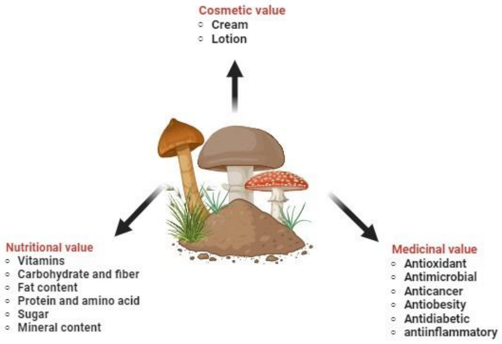

Fig 1: Advantages of mushroom and its potential applications

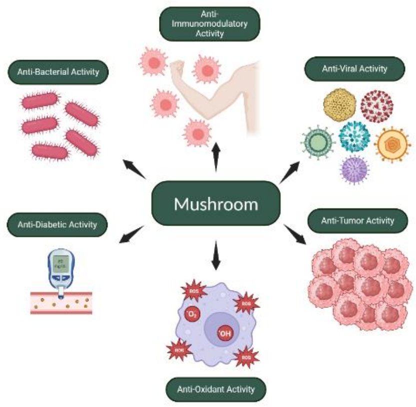

Fig 2: Various pharmacological activities of mushrooms

2.1 Bioactive compounds and Biological Benefits of Pleurotus genus (Oyster mushroom)

Numerous chemicals, including polysaccharides, lipopolysaccharides, proteins, peptides, glycoproteins, nucleosides, triterpenoids, lectins, lipids, and related materials, are among the active components of the Pleurotus ostreatus fungus. These components are essential for the mushroom's medicinal properties that can positively impact human health [28]. The Pleurotus genus, commonly known as oyster mushrooms, extends its biological benefits beyond mere edibility, showcasing a rich profile of bioactive compounds with diverse therapeutic potentials. These mushrooms are renowned for their immunomodulatory properties, as the beta-glucans present in Pleurotus species have been shown to enhance immune responses and exhibit anti-tumor activities. Additionally, they contain ergothioneine, a potent antioxidant that scavenges free radicals and helps mitigate oxidative stress. The presence of lovastatin in some species contributes to their cholesterol-lowering properties, supporting cardiovascular health. Moreover, Pleurotus mushrooms are rich in vitamins, minerals, and essential amino acids, making them a nutritious addition to diets. The bioactive compounds present in Pleurotus mushrooms have spurred research into their potential applications in pharmaceuticals, nutraceuticals, and functional foods, highlighting the versatility of this fungal genus beyond its culinary appeal. As ongoing studies delve deeper into their therapeutic potential, Pleurotus mushrooms hold promise for contributing to holistic health and well-being.

3. Mushroom Lectins

Similar to plant lectins, mushrooms make high levels of storage proteins called lectins. These proteins might be involved in defence. Further, lectins play an important role in mycorrhizas, lichens, and cell interactions, such as flocculation, mycelial aggregation and mating, in which fungi and other organisms form symbiotic relationships. It has also been discovered that lectins isolated from one mushroom species possess very different biochemical properties, such as varying molecular masses, varying subunit numbers, and differing carbohydrate specificities. It is possible to observe differences in lectin expression levels based on the growth season and the age of the fruit body, as well as the region where the mushroom is grown, including the caps, stalks, and mycelia [30]. Compared to adult mushrooms, young mushrooms have higher concentrations of lectin from Trichomopsis rutilans, Lactarius rufus, and Amanita muscaria, for example. Amanita phalloides, a hemolytic mushroom, was discovered as the first mushroom to produce lectin. There is evidence that lectin expression is affected by several environmental factors, such as season, location, and year, in addition to macroscale variables. Diverse mushroom species contain approximately 105 lectins [31]. Amanita, Pleurotus, Agaricus, Boletus, and Amanita have all been identified as having lectins in the most numbers. Agrocybe cylindracea, Laccaria amethystina, Agrocybe aegerita, Schizophyllum commune, and Coprinus cinereus, are some of the mushrooms from which more than one lectin has been isolated. Actinoporin-like folds are another unique feature of mushroom lectins. A helix-loop-helix motif connects two helix-loop-helix sheets with a fold similar to an actinoporin, which has a sandwich-like structure composed of six and four strands of each sheet, respectively. All lectins from the Xerocomus chrysenteron genus, as well as Agaricus bisporus genus, contain this fold. A single epimeric hydroxyl can be recognized by two lectin binding sites in dimers or tetramers per monomer [32]. LDL (Lyophyllum decastes lectin) is a new lectin that has been added to the mushroom lectin family and its sources as shown in Figure 3, 4 & 5. A recently determined LDL structure reveals the lectin has an unusual fold in which the core, which has two antiparallel sheets, connects to an intramolecular disulfide bridge on the perimeter. Additionally, unlike other mushroom lectins, LDL has an extracellular structure and fold [33]. Numerous researchers have studied mushroom lectins for their potential applications over the years. According to Hassan et al.,2021 [32], hundreds of mushroom lectins have been reviewed for their molecular, biochemical, structural, and potential applications. As a result of the interactions between lectins and glycoproteins, mushroom lectins possess mitogenicity, potent antiviral activity, modulation of immune cells, and therapeutic potential. Many studies have been conducted on the effectiveness of mushroom lectins as antiproliferative agents, immune stimulators, antimicrobials, antioxidants, and therapeutic agents [34].

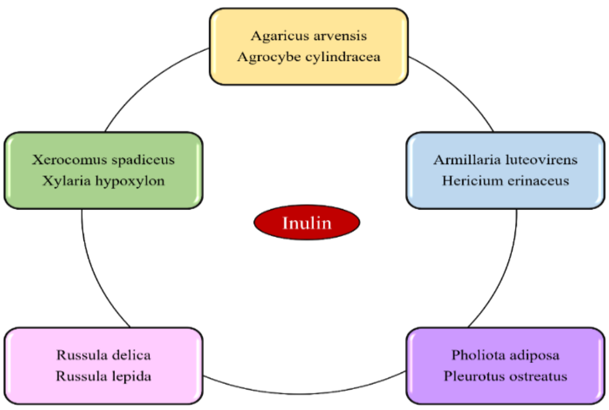

Fig 3: Source of Lectin from mushroom with inulin

Journal of Chemical Health Risks
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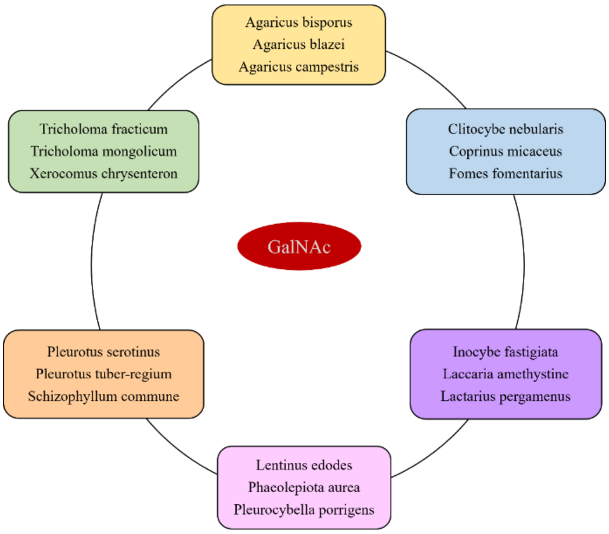

Fig 4: Source of Lectin from mushroom with GalNAc

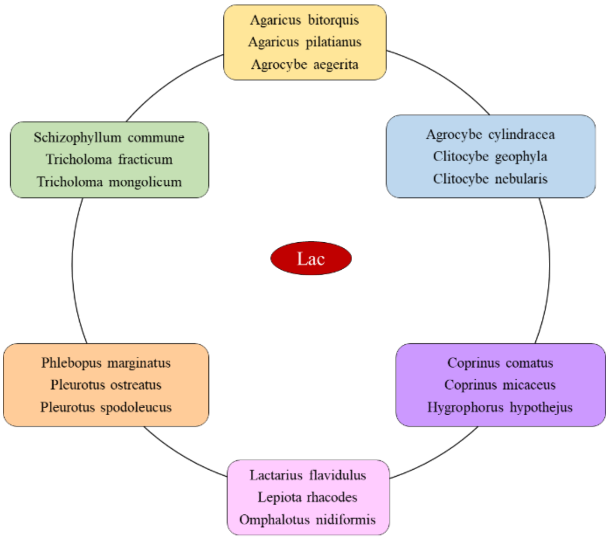

Fig 5: Source of Lectin from mushroom with Lac

4. Vitamin D metabolism in mushrooms

The classification system in biology recognises five distinct kingdoms, namely Animalia, Plantae, Fungi, Protista (which encompasses algae), and Monera (encompassing bacteria). According to the study conducted [35], In spite of their classification as a vegetable in culinary environments mushrooms are taxonomically classified as members of the fungal kingdom, distinct from both the plant and animal kingdoms. Compared to plants, mushrooms have far more ergosterol in their cell membrane. This sterol helps maintain cell membranes, controls membrane fluidity, and improves intracellular transport, just like cholesterol does in mammals. [36] After being exposed to ultraviolet light, the ergosterol in the mushroom cell wall is transformed to pre-vitamin D2, and then, in a temperature-dependent process, this pre-vitamin D2 is isomerized into the active form of vitamin D2, ergocalciferol [37][38]. All edible mushrooms contain the provitamin D4 that can be converted to vitamin D4 when exposed to UV radiation. D2 and D4 content tend to be found in mushrooms that have been exposed to UV light [39] (Figure 6).

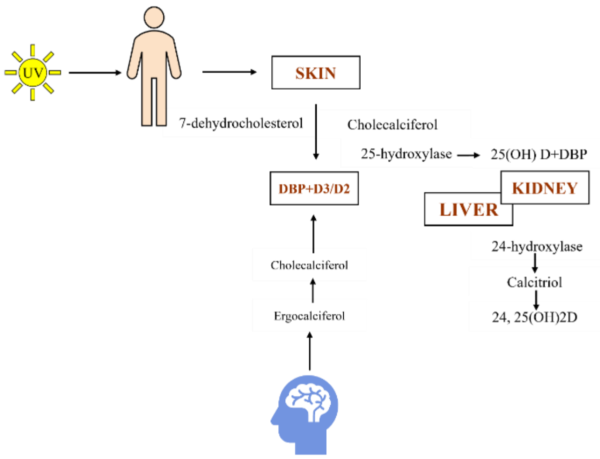

Fig 6: Conversion of UV rays from the sun (7-dehydrocholesterol) to Vitamin D 2&3 as a potential source from liver and kidneys

4.1 Vitamin D a source and intake of dietary

The nutritional and physiological advantages of mushrooms are many, ranging from their ability to aid in wound healing and immune system strengthening to their suppression of tumour growth. [40] Vitamin D, a fat-soluble vitamin, is crucial in keeping our bones, immune systems, and overall health in good shape. While exposure to sunlight enables our skin to produce vitamin D, dietary sources are still crucial, particularly in areas with little sun exposure or for those who have trouble absorbing the vitamin via their skin. Vitamin D2 (ergocalciferol) and vitamin D3 (cholecalciferol) are the two most common types of the vitamin. Vitamin D2 is found in some plant-based sources including mushrooms, enriched meals, and supplements, while vitamin D3 is predominantly acquired from animal sources such fatty fish like salmon and cod liver oil. Vitamin D is required for overall health, and getting enough of it from food is crucial. [26] A lot of individuals obtain their vitamin D3 requirements by eating fatty fish like salmon, mackerel, and sardines. Vitamin D3 is abundant in cod liver oil, with 450 international units (IU) per teaspoon. Those who avoid animal products may benefit greatly from consuming fortified meals such as cereals and milks made from plants. Vitamin D2 may be synthesised by mushrooms when they are exposed to UV light during growing, therefore they are a good alternative for vegans and vegetarians. Recommended dietary allowances (RDAs) for vitamin D intake, as determined by a US committee in 2011, can vary with age and other circumstances, although adults typically require between 600 and 800 international units (IU) per day. However, because everyone has somewhat different needs, it's best to talk to a doctor about specific suggestions. According to the National Institutes of Health in 2021, vitamin D is important for many physiological functions beyond only bone health.

4.2 Bioavailability of Vitamin D in Mushroom

Mushrooms are gaining interest as a possible plant-based dietary source of vitamin D, despite the fact that the bioavailability of vitamin D in mushrooms is often linked to sun exposure and animal-derived sources. It is essential for everyone, particularly vegetarians and vegans, to keep up their vitamin D levels, and recent studies have shed light on the factors that affect the bioavailability of vitamin D in mushrooms. The bioavailability of vitamin D in several types of mushrooms was recently studied. The vitamin D content of mushrooms was discovered to be greatly increased after being exposed to ultraviolet (UV) radiation. Specific types of mushrooms that have been exposed to UV light during cultivation exhibit increased levels of vitamin D. Among these, Agaricus bisporus, commonly known as white button mushrooms, have been studied extensively for their ability to accumulate vitamin D2 when exposed to UV light. Research conducted by [41] demonstrated that exposing these mushrooms to UV light for a sufficient duration enhances their vitamin D content significantly. Furthermore, other varieties such as shiitake (Lentinula edodes) and maitake (Grifola frondosa) mushrooms have also been reported to accumulate vitamin D2 when exposed to UV light [42]. It's important to note that the vitamin D content in mushrooms can vary based on cultivation and processing methods, so consumers should check labels or consult reliable sources for accurate information. Mushrooms that have been exposed to ultraviolet light are able to give a significant quantity of vitamin D when consumed. The study further found that the absorption of vitamin D was improved with prolonged exposure durations to UV radiation, regardless of the intensity of the light. In addition, the capacity to synthesise vitamin D following exposure to UV light is facilitated by the presence of ergosterol, a precursor to vitamin D, in mushroom. Mushrooms are a good alternative to vitamin D from animals because of this special property that sets them different from other plant-based sources of vitamin D. While certain mushrooms are better than others at producing accessible vitamin D, it's important to be aware that not all mushrooms are produced alike. The vitamin D concentration in mushrooms can vary depending on the type of mushroom, how it was grown, and how it was treated after harvest. To get the most vitamin D out of your diet, it's best to either consume mushrooms that have been deliberately exposed to UV radiation or to carefully examine nutrition labels. Recent studies have shown that mushrooms can synthesise vitamin D, making them a good option for people with dietary limitations or those looking for different ways to get enough of this crucial ingredient. The increasing interest in mushrooms as a result of their nutritional potential calls for more research into the specific circumstances and variables that impact the bioavailability of vitamin D in mushrooms.

4.3 Ergosterol in mushrooms and its conversion to Vitamin D2

The amount of ergosterol found in produced mushrooms varies with both the type of mushroom being grown and the materials used to cultivate them. [43] Many research has been conducted since the 1970s, when scientists first began investigating ergosterol in fungus. Most fungus have high levels of the vitamin D2 precursor ergosterol. [44] Ergosterol is the most common sterol in mushrooms, and studies have revealed that the number of farmed mushrooms

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is higher than that of wild mushrooms. [43] The concentration of ergosterol ranged from 7.80 mg/g dry matter (DM) in button mushrooms to 0.68 mg/g DM in enoki mushrooms. Oyster mushrooms contained 4.40 mg/g of DM, whereas abalone mushrooms contained 4.35 mg/g. The ergosterol concentration in shiitake mushrooms was 6.05 0.07 mg/g dried weight. [45] The amounts of ergosterol in different kinds of non-irradiated mushrooms are shown in Figure 7. The amount of vitamin D2 in different types of mushrooms that were exposed to UV-A light beam for a set amount of time, with the gills towards the light source.

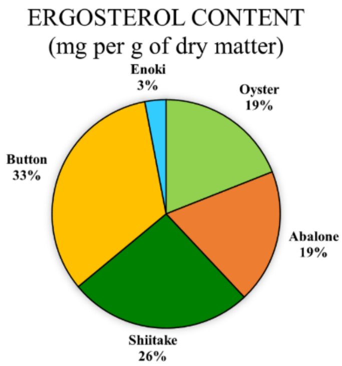

Fig 7: Differences in ergosterol levels across different mushroom varieties

4.4 UV- Irradiated mushrooms

Mushrooms that have been exposed to ultraviolet (UV) radiation have become popular in recent years due to their claimed health advantages and distinctive qualities. Several fascinating after-effects are seen when UV light, especially UVB and UVC, is applied to mushrooms. The nutritional value, therapeutic efficacy, and sensory qualities are all boosted as a result. The increase in vitamin D concentration is a notable aftereffect of UV irradiation on mushrooms. Ergosterol, a substance found in mushrooms, may be transformed into vitamin D2 (ergocalciferol) when exposed to UVB light [38]. Since vitamin D is necessary for bone health and immunological function, a boost in one's vitamin D levels might be especially helpful for those who don't get much sun. Researchers have shown that being out in the sun raises levels of antioxidant-rich bioactive molecules including ergothioneine and glutathione [40]. These antioxidants may benefit human health by preventing cell damage caused by oxidative stress. Mushrooms' taste and scent are impacted by UV irradiation as well. UV-treated mushrooms have been shown to have enhanced flavour and fragrance, according to studies [46]. UV irradiation mushrooms have also showed promising functional food with potential medical benefits. After being exposed to ultraviolet light, polysaccharides like beta-glucans have been shown to increase [47]. The immune-modulating effects of beta-glucans and their therapeutic potential in cancer treatment are well-known.

5. Pharmacological activities related with mushroom

5.1 Immunomodulatory Activity

The immune system is our body's natural defence against a wide array of pathogens, including viruses, bacteria, and cancer cells. Modulating the immune response can have profound implications for maintaining health and fighting diseases. Mushroom lectins, a class of carbohydrate-binding proteins, have been found to have immunomodulatory properties. These lectins can affect various components of the immune system, making them promising candidates for therapeutic applications [48]. The immunomodulatory properties of mushroom lectins hold great potential for various clinical applications. Researchers are actively exploring their use in cancer immunotherapy, infectious disease management, and autoimmune disease treatment. Clinical trials and laboratory studies have shown that mushroom lectins can enhance the efficacy of vaccines, improve immune responses in immunocompromised individuals, and potentially contribute to the treatment of conditions such as HIV and cancer [49]. Immunological activities are known to be exhibited by a few mushroom lectins. Monocytes, lymphocytes, and macrophages can be stimulated to proliferate in mouse spleens by fungal immunomodulatory proteins. Boosting production of cytokines by type 1 T helper cells (Th-1) and inhibiting allergic reactions are two of their properties. Several recent reports indicate that Latiporus sulphureus lectin interacts with toll-like receptor-4, promoting the production of tumor necrosis, nitric oxide and cytokines, factors through macrophages. Physiological functions of nitric oxide in the immune system include protection against pathogenic microorganisms. TNFA plays a role in cell proliferation, differentiation, apoptosis, and inflammation. In addition to increasing cytokine secretion, immunomodulatory lectins protect host cells from various pathogens. Agaricus bisporus lectin, despite acting on both innate and adaptive immunity, exhibits a remarkable inhibitory effect on macrophages [50]. The O-glycans on the surface of macrophages contain both T-antigen and sialyl-T antigen residues, which modulate the downstream Akt pathway via Agaricus bisporus lectins. Mushroom lectins regulate immune response primarily through macrophage involvement through an interaction between lectin and A. bisporus glycan. Akt phosphorylation is inhibited by lectin-glycan interaction, which inhibits nitric oxide and cytokine production. During tumors, infections, and inflammations, macrophages pass by distorted cells to phagocytose and act as the first line of defense [51]. Macrophages are activated when lectin binds to receptors on the surface of cells (such as toll-like receptors). Nitric oxide is then induced and released as well as interleukin factors (IL-6, IL-1α, IL-1 β and IL-10) and tumor necrosis factor-α. Immune responses are modulated or suppressed by cytokines released by inflammation cells such as eosinophils, neutrophils, basophils, and monocytes/macrophages. The production of interleukin (IL-2) and interferon by T helper cells (Th1) is induced by lectin subset-induced upregulation of these cytokines. Cytokines are regulated and produced by mushroom lectins, which have immunomodulatory effects. Leptin binding to glycans over target cells is thus implicated in causing immunomodulatory effects. As a result, various cytokines are produced and nitric oxide is enhanced, leading to downstream signaling and activation of macrophages. It is evident that lectin-based interactions play a role in modulating immune responses and have potential usages as macological agents and in understanding immunological mechanisms associated with immune-related illnesses [52]. The binding of lectin to glycan over target cells is thus a crucial step involved in inducing immunomodulatory effects. By doing so, macrophages are activated and downstream signaling occurs, resulting in cytokine production and nitric oxide production being enhanced. In addition to modulating immune response, lectin-based interactions can provide potential candidates for pharmacological applications in the treatment of immune-related diseases and for understanding the immunology processes involved in them [51]. Anti-immunomodulatory activity currently, immune-modulating agents represent the most crucial medicinal mushroom treatments, commonly administered in China, Japan, Korea, and other nations across East Asia [53]. A wide range of components, includes polysaccharides, lectins, proteins and peptide were isolated from P. ostreatus, as revealed [54]. These components have been identified to possess immunomodulatory effects [55][56] claim that P. ostreatus fruit bodies and mycelia water extracts both contribute to the increased production of ROS by neutrophils. Moreover, it exhibits immuno-modulatory properties that impact all cells with immune competence. According to [57] the oyster mushroom's immune-modulatory characteristics, along with its low cytotoxicity, have increased the possibility that it could be beneficial for cancer patients.

5.2 Anti-oxidant activity

Phenolic compounds are fundamental agents for carrying antioxidants, wherein polyphenols possess the capability to donate electrons and hydrogen atoms to disrupt and neutralize chains of free radicals [58]. [59] underscored that oxidative stress significantly contributes to the development of diverse degenerative illnesses, including cancer and hepatotoxicity. Compounds such as phenols and flavonoids, which possess antioxidant properties, can impede the elements responsible for inducing oxidative stress. Furthermore, Ethanolic extracts from the oyster mushroom showed significant antioxidant activity in both in vitro and in vivo investigations, according to research [60] [61] further emphasized that compared to PSPO-4a, PSPO-1a exhibited superior abilities in scavenging free radicals among the two polysaccharides. Moreover, Mitra et al., highlighted those water-soluble polysaccharides extracted from P. ostreatus exhibited exceptional antioxidant properties primarily assigned to the existence of the component of carbohydrates, namely β-glucan. Oyster mushroom water extract is effective against 2,2'-azinobis-(3-ethylbenzthiazoline-6-sulphonate) (ABTS) cation radicals, 1,1-diphenyl-2-picrylhydrazyl (DPPH) radicals, and oxygen radical absorbance capacity

(ORAC) [62]. Simultaneously, research has demonstrated that oyster mushroom protein demonstrates a robust antioxidant potential after protease hydrolysis, including roles like OH scavenging, metal chelation, DPPH and ABTS scavenging, and suppression of linoleic acid self-oxidation [62]. Certain research has involved the fermentation of oyster mushrooms and their incorporation into cookies, validating an increased antioxidant capacity [63].

5.3 Anti-bacterial activity

The most often given medications in human medicine are antibiotics. Approximately 50% of all antibiotics given to patients are either unnecessary or ineffective when taken as directed. The movement of antibiotic-resistant bacterial strains from one person to another or from environmental elements that aren't related to people, such food, is another important element in the development of antibiotic resistance [64]. Natural resources have been used over time, and one of them is the abundance of active compounds with nutritional and antimicrobial activities found in wild edible mushrooms. For a long time, mushrooms have played a crucial part in a variety of activities and have been valuable for medicine. They are also needed for food and have many other uses that are important to human activity. During in vitro testing, the macro fungus extracted with petroleum was found to have broad-spectrum antibacterial capabilities as it inhibited the development of both Gram +ve and Gram -ve bacteria [65]. P. ostreatus mycelium has been employed in antimicrobial research, utilizing water and alcohol extracts, as documented [66]. According to Chowdhury et al.,[67] the P. ostreatus mycelium's methanolic extract showed efficacy against Gram +ve and Gram -ve bacteria, with a MIC that ranged from 4 - 8 µg mL -1. [68] demonstrated that organic extracts of P. ostreatus using methanol and chloroform displayed effectiveness against Gram-positive bacteria, highlighting their potential as antibacterial agents. In follow-up research carried out [55]. Evaluated the antibacterial activity of silver nanoparticles made from P. ostreatus and oyster mushrooms against a variety of Gram-positive bacteria by measuring the widths of their inhibition zones. Among all the examined microorganisms, the AgNPs generated using P. ostreatus showed the largest inhibitory zones. Existence antimicrobial activity against gram positive bacteria and gram-negative bacteria. Gram-negative and Gram-positive bacteria play crucial roles in the symbiotic relationships formed with mushrooms, contributing to the overall health and ecological function of these fungi. In mycorrhizal associations, where mushrooms form partnerships with plant roots, bacteria associated with the mycorrhizal networks influence nutrient cycling, plant growth, and soil health. There have been several reports of mushroom extracts showing antimicrobial properties against gram-positive bacteria (Table 1) and gram-negative bacteria (Table 2). L. laccata was dissolved in ethanol and has the most effective treatment against S. aureus at a concentration of 50 g/mL. At 100 g/mL extract concentration, it shown efficacy against E. coli, A. baumannii, Candida albicans, Candida krusei, and Candida glabrata. It shown efficacy against at 200 g/mL extract concentration in E. faecalis and P. aeruginosa. By the result, L. laccata was shown to have antibacterial and antifungal properties [69] [70] methanolic extract reported that MIC varied from 2.09 to 16.75 mg/mL. E. coli (T. robustus), S. typhimurium (T. ochracea), and C. diphtheriae (T. ochracea) had the lowest values (2.09 mg/mL), but C. albicans (L. squarrosulus and T. ochracea extracts) had the highest (16.75 mg/mL). Their report contradicts the previous study finding of a low MIC for the fungus species. For gram-positive bacteria, the MIC values were from 20 mg/mL to 0.156 mg/mL, whereas the values ranged from 20 mg/mL to 0.625 mg/mL for gram-negative bacteria [65]. For both Gram-positive and Gram-negative isolates, the ethanol extracts of I. hispidus, L. fragrans, and P. tinctorius typically stood out, with lower MIC values, which respectively suggest a better antimicrobial effect. I. hispidus is the species that has been the most research in antimicrobial activity [71]. A. mellea ethanolic extract's MIC ranged from 62.50 to 250 mg/ml. methanolic extracts of A. mellea MIC ranged from 62.5 to 125 mg/ml. A. mellea's aqueous extract has a MIC of 125 mg/ml. methanolic extract of A. mellea in C. glabrata

Journal of Chemical Health Risks
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JCHR (2024) 14(2), 1463-1484 | ISSN:2251-6727

Table 1: Antibacterial activity of mushrooms (Gram-Positive bacteria)

Micro organism	Mushroom	Solvent	MIC Result(mg/mL)	Reference
S. aureus	*Laccaria laccata*	Ethanol	50	[66]
	Trametes ochracea	Methanol	8.38	[67]
	Butyriboletus regius	Ethanol	5	[68]
	Ganoderma lucidum	Ethanol	5	[68]
	Inonotus hispidus	Ethanol	0.625	[68]
	Lanmaoa fragrans	Ethanol	0.312	[68]
	Pisolithus tinctorius	Ethanol	0.625	[68]
	Suillellus luridus	Ethanol	5	[68]
	Xerocomus subtomentosus	Ethanol	20	[68]
	Suillellus mendax	Ethanol	5	[68]
	Armillria mellea	Ethanol	62.5	[69]
	Armillria mellea	Methanol	125	[69]
	Armillria mellea	Aqueous	125	[69]
	Bovista nigrescens	Ethanol	50	[70]
	Bovista nigrescens	Methanol	100	[70]
E. coli	*Laccaria laccata*	Ethanol	100	[66]
	Termitomyces robustus	Methanol	2.09	[67]
	Trametes ochracea	Methanol	4.19	[67]
	Xylaria hypoxylon	Methanol	4.19	[67]
	Butyriboletus regius	Ethanol	10	[68]
	Ganoderma lucidum	Ethanol	20	[68]
	Inonotus hispidus	Ethanol	5	[68]
	Lanmaoa fragrans	Ethanol	2.5	[68]
	Pisolithus tinctorius	Ethanol	5	[68]
	Suillellus luridus	Ethanol	10	[68]

Journal of Chemical Health Risks
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JCHR (2024) 14(2), 1463-1484 | ISSN:2251-6727

	Suillellus mendax	Ethanol	10	[68]
	Xerocomus subtomentosus	Ethanol	20	[68]
	Armillria mellea	Ethanol	250	[69]
	Bovista nigrescens	Ethanol	100	[70]
	Bovista nigrescens	Methanol	200	[70]
E. faecalis	*Laccaria laccata*	Ethanol	200	[66]
	Bovista nigrescens	Ethanol	100	[70]
	Bovista nigrescens	Methanol	200	[70]
C. albicans	*Laccaria laccata*	Ethanol	100	[66]
	Lentinus squarrosulus	Methanol	16.75	[67]
	Termitomyces robustus	Methanol	8.38	[67]
	Trametes ochracea	Methanol	16.75	[67]
	Armillria mellea	Ethanol	62.5	[69]
	Armillria mellea	Aqueous	31.25	[69]
	Bovista nigrescens	Ethanol	100	[70]
	Bovista nigrescens	Methanol	200	[70]
C. glabrata	*Laccaria laccata*	Ethanol	100	[66]
	Armillria mellea	Methanol	62.5	[69]
	Armillria mellea	Aqueous	31.25	[69]
	Bovista nigrescens	Ethanol	100	[70]
	Bovista nigrescens	Methanol	100	[70]
C. krusei	*Laccaria laccata*	Ethanol	100	[66]
	Bovista nigrescens	Ethanol	100	[70]
	Bovista nigrescens	Methanol	200	[70]
B. subtilis	*Trametes ochracea*	Methanol	4.19	[67]
	Xylaria hypoxylon	Methanol	8.38	[67]

C. diphtheriae	*Trametes ochracea*	Methanol	2.09	[67]
E. faecium	*Butyriboletus regius*	Ethanol	20	[68]
	Ganoderma lucidum	Ethanol	20	[68]
	Inonotus hispidus	Ethanol	5	[68]
	Lanmaoa fragrans	Ethanol	2.5	[68]
	Pisolithus tinctorius	Ethanol	5	[68]
	Suillellus luridus	Ethanol	10	[68]
	Suillellus mendax	Ethanol	20	[68]
	Xerocomus subtomentosus	Ethanol	20	[68]
B. cereus	*Armillria mellea*	Methanol	62.5	[69]
	Armillria mellea	Aqueous	125	[69]

MIC was reported 62.5 mg/ml. The MIC of an aqueous extract of A. mellea for C. albicans was 31.25 mg/ml [72]. The ethanolic and methanolic extracts of B. nigrescens extracts were tested for their ability to fight against bacterial and fungal strains [73].

5.4 Antiviral Activity

Various viral infections are being treated by mushroom lectins, which have been studied by researchers in lectinology. As they cause various infectious diseases, viruses pose a significant threat to human health. The increasing emergence of drug-resistant viral strains has

Table 2: Antibacterial activity of mushrooms (Gram-Negative bacteria)

Micro organism	Mushroom	Solvent	MIC Result(mg/mL)	Reference
P. aeruginosa	*Laccaria laccata*	Ethanol	200	[66]
	Lentinus squarrosulus	Methanol	8.38	[67]
	Butyriboletus regius	Ethanol	10	[68]
	Ganoderma lucidum	Ethanol	20	[68]
	Lanmaoa fragrans	Ethanol	20	[68]
	Pisolithus tinctorius	Ethanol	5	[68]
	Suillellus luridus	Ethanol	10	[68]
	Suillellus mendax	Ethanol	20	[68]

	Xerocomus subtomentosus	Ethanol	20	[68]
	Armillria mellea	Ethanol	62.5	[69]
	Bovista nigrescens	Ethanol	200	[70]
	Bovista nigrescens	Methanol	400	[70]
K. pneumoniae	*Termitomyces robustus*	Methanol	4.19	[67]
	Trametes ochracea	Methanol	8.38	[67]
	Butyriboletus regius	Ethanol	10	[68]
	Inonotus hispidus	Ethanol	10	[68]
	Lanmaoa fragrans	Ethanol	10	[68]
	Pisolithus tinctorius	Ethanol	5	[68]
	Xerocomus subtomentosus	Ethanol	20	[68]
	Ganoderma lucidum	Ethanol	20	[68]
	Suillellus mendax	Ethanol	10	[68]
	Suillellus luridus	Ethanol	10	[68]
S. typhimurium	*Termitomyces robustus*	Methanol	4.19	[67]
	Trametes ochracea	Methanol	2.09	[67]
	Xylaria hypoxylon	Methanol	8.38	[67]
P. mirabilis;	*Trametes ochracea*	Methanol	4.19	[67]
A. baumannii	*Butyriboletus regius*	Ethanol	20	[68]
	Inonotus hispidus	Ethanol	10	[68]
	Lanmaoa fragrans	Ethanol	0.625	[68]
	Suillellus luridus	Ethanol	10	[68]
	Xerocomus subtomentosus	Ethanol	20	[68]
	Pisolithus tinctorius	Ethanol	10	[68]
	Suillellus mendax	Ethanol	10	[68]
	Ganoderma lucidum	Ethanol	10	[68]
	Laccaria laccata	Ethanol	100	[66]
	Bovista nigrescens	Ethanol	100	[70]
	Bovista nigrescens	Methanol	100	[70]

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 1463-1484 | ISSN:2251-6727

E. aerogenes	*Butyriboletus regius*	Ethanol	10	[68]
	Inonotus hispidus	Ethanol	10	[68]
	Lanmaoa fragrans	Ethanol	1.25	[68]
	Suillellus luridus	Ethanol	10	[68]
	Pisolithus tinctorius	Ethanol	5	[68]
	Suillellus mendax	Ethanol	20	[68]
	Ganoderma lucidum	Ethanol	10	[68]

fuelled the search for novel antiviral agents. Mushroom lectins have gained recognition for their ability to interfere with viral infections, exhibiting potential in preventing, treating, and mitigating viral diseases [74]. There are several mechanisms by which mushroom lectins exert their antiviral effects. Their primary mechanism involves inhibiting viral attachment to host cells and entry into them. Viral infection is prevented by lectins by binding to glycoproteins on viral envelopes or to cell receptors on host cells.Moreover, mushroom lectins can inhibit viral replication by interfering with viral protein synthesis, transcription, or translation within infected cells. They may disrupt the viral life cycle by inhibiting critical processes like protein glycosylation, which is essential for viral infectivity [75]. Another, intriguing aspect of mushroom lectins is their immunomodulatory properties. They can enhance the host immune response, stimulating the production of cytokines and activating immune cells, which aid in combating viral infections [74]. Paxillus involutus lectin, its antiphytovirus activity against tobacco mosaic virus is inhibited by 70.6%, whereas neither it nor HIV-1 reverse transcriptase are inhibited. As opposed to Hericium erinaceus agglutinin, Hericium erinaceus agglutinin has been shown to suppress reverse transcriptase HIV-1 activity with an IC50 of 31.7 M. Several lectins found in mushrooms suppress reverse transcription of HIV-1. There are several lectins which are able to inhibit HIV-1 reverse transcription, including Schizophyllum commune lectin, ABL, Pleurotus citrinopileatus lectin, BEL, Inocybe umbrinella lectin and Cordyceps militaris lectin. According to a study revealed by the National Institutes of Health, Pleurotus citrinopileatus (PCL) exhibits the highest activity against HIV-1 reverse transcriptase [76]. In general, it is unclear how lectins inhibit HIV-1 reverse transcriptase, but they are likely to have inhibitory effects through protein-protein interactions, as has been found for protease HIV-1, which inhibits HIV-1 reverse transcription as well. The HIV-1 reverse transcriptase is also suppressed by ribosome inactivating proteins, plant lectins and antifungal proteins, in addition to mushroom lectins. Agglutinin, along with the well-studied concanavalin A lectin and ricin lectin, inhibit the beta and alpha activities of DNA polymerase. A comparison of this activity with that of other lectins and their suppression of reverse transcription needs to be determined [77]. In addition to fungi lectins, mushroom lectins such as CVNHs (cyanovirin-N homologs), are antimicrobial. Among these lectins, scytovirin, microcystis virdis lectin and griffithsin demonstrated more efficiency than cyanovirin-N of native bacteria and other well-known inhibitors of virus replication. In addition to interacting with cell surface receptors, cyanovirin-N also interacts with viral envelope glycoprotein 120. Nevertheless, the significance of this mechanism in relation to other lectins' anti-HIV activity remains uncertain [78]. Antiviral therapy entails the use of specific antiviral substances to hinder the replication of viruses in humans while leaving regular cell division unaffected. Therefore, it is crucial to discover and create novel antiviral compounds that do not produce adverse effects in humans and can also mitigate viral resistance. Complete extracts of dietary oyster mushrooms as well as specific components isolated from them are credited as having antiviral characteristics. Since ordinary antibiotics cannot effectively treat viral illnesses, specific drugs are

JCHR (2024) 14(2), 1463-1484 | ISSN:2251-6727

desperately needed [79] [80] reported that they had extracted a laccase from oyster mushrooms that showed promise in blocking the entry of the Hepatitis C virus into hepatoma HepG2 cells as well as peripheral blood cells. It also prevented the virus from replicating. A further ubiquitin-like protein from P. ostreatus was discovered by Wang [54]; this protein has inhibitory effects on the HIV-1 reverse transcriptase.

5.5 Anti-diabetic activity

Oyster mushrooms are low in fat and high in dietary fiber, and protein, including them in your diet can help you prevent hyperglycemia [80]. P. ostreatus has been shown to blood glucose levels by activating glucokinase, insulin secretion stimulation, and glycogen synthase kinase inhibition, all of which increase the production of glycogen [67]. According to Krishna and Usha in 2009, In both diabetic 1 and diabetic 2, P. ostreatus and other mushrooms, such as Murraya Koenigii, combined to reduce blood glucose levels synergistically. P. ostreatus extract was also shown [59] to reduce blood sugar levels in hyperglycemic rats, even though less effective than Amaryl therapy. Research involving human participants has explored the hypoglycemic benefits of P. ostreatus. According to a study, when 3g of mushroom powder was added to the food for 3 months, the BP, HbA1c, and fasting blood sugar levels of twenty-seven patients with hypertension and diabetes all decreased. Furthermore, following oral administration of a glucose solution, the fasting glucose levels of twenty-two healthy persons were found to be lower after being given powdered P. ostreatus [67].

5.6 Anti-tumor activity

Different extracts obtained from oyster mushrooms have been suggested as possible agents with anti-cancer properties. However, their effectiveness in actual medical and clinical applications for treating cancer is yet to be fully confirmed [54]. The initial documentation of the anti-cancer effects of the polysaccharide fraction of P. ostreatus was provided [82]. As indicated in reference [83] the growth of human breast cancer cells was inhibited by the hot water extract obtained from oyster mushrooms. Clinical trials have been conducted on compounds found in P. ostreatus mushrooms that inhibit tumor activity [84]. Furthermore, as noted edible mushrooms of all kinds have the potential to prevent breast and prostate cancer. Various extracts originating from P. ostreatus have documented their anti-cancer capabilities across various cancer cells and animal model experiments, exhibiting diverse mechanisms of action. As noted in the reference, the water-soluble extracts from P. ostreatus showed the strongest cytotoxic effects and induced apoptosis in human androgen-independent PC-3 (prostate cancer) cells [85].

5.7. Beta-Glucans and mushrooms

Beta-glucans are polysaccharides found in the cell walls of various fungi, including mushrooms. These compounds have gained significant attention due to their potential health benefits. Research suggests that beta-glucans from mushrooms possess immunomodulatory properties, enhancing the activity of immune cells and promoting a more robust immune response [86]. Additionally, they have been linked to potential anti-inflammatory effects and may contribute to the management of certain chronic conditions. The structure of beta-glucans can vary among mushroom species, influencing their biological activities. Notable mushroom varieties rich in beta-glucans include shiitake (Lentinula edodes), maitake (Grifola frondosa), and reishi (Ganoderma lucidum). While more studies are needed to fully understand the extent of their health benefits, incorporating mushrooms into the diet can be a natural way to access these potentially advantageous compounds [87].

6. Conclusion

Mushrooms have a long and rich history of use as food, medicine, and cultural icons. In recent years, there has been a growing interest in the nutritional and therapeutic properties of mushrooms. Research has shown that mushrooms contain a variety of physiologically active substances with potential effects on cardiovascular health, hepatoprotection, anticancer and immunomodulation, antiviral and antibacterial properties, hypocholesterolemia, and antitumor activities. One of the most well-studied genera of mushrooms is Pleurotus, which is known for its ligninolytic capabilities and its abundance of bioactive compounds. Pleurotus species are also edible and offer a variety of biological benefits. Another important finding is that some mushroom species can produce significant quantities of vitamin D when exposed to ultraviolet (UV) radiation. This makes mushrooms a valuable dietary source of vitamin D, especially for people who do not get enough sun exposure. Overall, the available evidence suggests that mushrooms are a nutritious and potentially therapeutic food. More research is needed to fully understand the pharmacological potential of mushrooms and their compounds, but the current findings are encouraging. Future research on mushrooms in medicine and nutrition holds great promise, as these fungi exhibit a myriad of bioactive compounds with potential health benefits. Understanding the intricate interplay between mushroom-derived compounds and human physiology could unveil novel therapeutic applications. Mushrooms are rich in beta-glucans, polysaccharides, and antioxidants, which have demonstrated immunomodulatory and anti-inflammatory properties. Future their impact on immune function, metabolic health, and neuroprotection could pave the way for innovative interventions in chronic diseases. Additionally, investigating the symbiotic relationships between mushrooms and gut microbiota may offer insights into improving digestive health. Harnessing the nutritional value of mushrooms, such as their protein content and unique micronutrients, may contribute to addressing global food security challenges. As researchers delve deeper into the untapped potential of mushrooms, the development of functional foods, dietary supplements, and pharmaceuticals could revolutionize healthcare, providing sustainable and natural solutions for a range of health issues. Developing clinical trials to test the efficacy and safety of mushroom extracts and compounds in the treatment and prevention of various diseases. Investigating the synergistic effects of different mushroom species and compounds. Developing new ways to cultivate and produce mushrooms that are high in bioactive compounds and vitamin D.

Abbreviations

UV : Ultraviolet

DM : Dry matter

LMW : Low molecular weight

HMW : High molecular weight

DPPH : Diphenyl-2-picrylhydrazyl

ORAC : Oxygen radical absorbance capacity

TNFA : Tumor necrosis factor alpha

CVNHs : Cyanovirin-N homologs

Acknowledgments

The authors would like to thank to the management of Chettinad Academy of Research and Education (Deemed to be University) for providing facilities to perform this study.

Authors Contribution

All authors contributed to this work, read and approved the final draft.

Ethical Approval

No ethical approval was required for the study. Since the present study was categorized as review article, patient consent forms are not required.

Funding

This study did not receive any funding in any form.

Consent for publication

Not applicable

Declaration of Competing Interest

The authors declare that there is no competing of interest regarding the publication of this article.

References

1. Sommano SR, Suksathan R, Sombat T, Seehanam P, Sirilun S, Ruksiriwanich W, Wangtueai S, Leksawasdi N. Novel Perspective of Medicinal Mushroom Cultivations .A Review

Journal of Chemical Health Risks
www.jchr.org
JCHR (2024) 14(2), 1463-1484 | ISSN:2251-6727

Case for ‘Magic’Mushrooms. Agronomy. 2022 ;15:12(12):3185.

2. Samsudin NI, Abdullah N. Edible mushrooms from Malaysia. A literature review on their nutritional and medicinal properties. International Food Research Journal. 2019;26(1):11-31.
3. De Mattos-Shipley KM, Ford KL, Alberti F, Banks AM, Bailey AM, Foster GD. The good, the bad and the tasty: the many roles of mushrooms. Studies in mycology. 2016; 1:85(1):125-57.
4. Pal M, Berhanu G, Desalegn C, Kandi V. Severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2): an update. Cureus. 2020; 26:12(3).
5. Richman DD, Nathanson N. Antiviral therapy. In Viral pathogenesis. Academic Press. 2016;1: 271-287.
6. Hu D, Yang X, Hu C, Feng Z, Chen W, Shi H. Comparison of ergosterol and Vitamin D2 in mushrooms agaricus bisporus and Cordyceps militaris using ultraviolet irradiation directly on dry powder or in ethanol suspension. ACS omega. 2021 26;6(44):29506-15.
7. Dimitrijevic M, Jovanovic V. S, Cvetkovic J, Mihajilov Krstev T, Stojanovic G, & Mitic V. Screening of antioxidant, antimicrobial and antiradical activities of twelve selected Serbian wild mushrooms. Analytical Methods.2015; 7(10): 4181–4191.
8. Tabbouche SA, Gürgen A, Yildiz S, Kilic AO, Sokmen M. Antimicrobial and antiquorum sensing activity of some wild mushrooms collected from Turkey. MSU J Sci. 2017;5(2):4537.
9. Chelela B, Chacha M, Matemu A. Antibacterial and antifungal activities of selected wild mushrooms from Southern Highlands of Tanzania. American Journal of Research Communication. 2014; 2(9): 58-68.
10. Dimitrijevic M, Stankov Jovanovic V, Cvetkovic J, Mitic M, Petrovic G, Dordevic A & Mitic V. Phenolics, Antioxidant Potentials, and Antimicrobial Activities of Six WildBoletaceaeMushrooms. Analytical Letters.2017; 50(10): 1691–1709.
11. Boonsong S, Klaypradit W, Wilaipun P. Antioxidant activities of extracts from five edible mushrooms using different extractants. Agriculture and Natural Resources. 2016; 1:50(2):89-97.
12. Mwangi RW, Macharia JM, Wagara IN, Bence RL. The antioxidant potential of different edible and medicinal mushrooms. Biomedicine & Pharmacotherapy. 2022; 1: 147:112621.
13. Valverde ME, Hernandez-Perez T, Paredes-Lopez O. Edible mushrooms. improving human health and promoting quality life. International journal of microbiology. 2015; 376387.
14. Rai M, Paudel N, Sakhrie M, Gemmati D, Khan IA, Tisato V, Kanase A, Schulz A, Singh AV. Perspective on quantitative structure–toxicity relationship (QSTR) models to predict hepatic biotransformation of xenobiotics. Livers. 2023 Aug 30;3(3):448-62.
15. Mandelker L. Introduction to oxidative stress and mitochondrial dysfunction. Veterinary Clinics of North America. Small Animal Practice. 2008 ;38(1):1-30.
16. Shahzad F, Anderson D, Najafzadeh M. The antiviral, anti-inflammatory effects of natural medicinal herbs and mushrooms and SARS-CoV-2 infection. Nutrients. 2020;12(9):2573.
17. Bach F, Zielinski A. A. F, Helm C. V, Maciel G. M, Pedro A. C, Stafussa A. P, Avila S & Haminiuk C. W. I. Bio compounds of edible mushrooms: in vitro antioxidant and antimicrobial activities. LWT.2019; 107: 214–220.
18. Alves M, Ferreira I, Dias J, Teixeira V, Martins A & Pintado M. A Review on Antimicrobial Activity of Mushroom (Basidiomycetes) Extracts and Isolated Compounds. Planta Medica.2012;78(16): 1707–1718.
19. Cardwell G, Bornman JF, James AP, Black LJ. A review of mushroom as a potential source of dietary vitamin D.Nutrients.2018;10(10):1498.
20. Holick MF. Resurrection of vitamin D deficiency and rickets. J Clin Invest 2006; 116:2062-72.
21. Rajakumar K. Vitamin D, cod-liver oil, sunlight, and rickets: a historical perspective. Pediatrics. 2003; 112:e132-5.

22. Theodoratou E, Tzoulaki I, Zgaga L, Ioannidis J.P.A. Vitamin D and multiple health outcomes: Umbrella review of systematic reviews and meta-analyses of observational studies and randomised trials. BMJ. 2014; 348: g2035.
23. Girgis C.M, Clifton-Bligh R.J, Hamrick M.W, Holick M.F, Gunton J.E. The roles of vitamin D in skeletal muscle: Form, function, and metabolism. Endocr. Rev. 2013; 34: 33–83.
24. Hossein-nezhad A, Holick M.F. Vitamin D for health: A global perspective. Mayo Clin. Proc. 2013; 88: 720–755.
25. Ford J.A, MacLennan G.S, Avenell A, Bolland M, Grey A, Witham M, Group R.T. Cardiovascular disease and vitamin D supplementation: Trial analysis, systematic review and meta-analysis. Am. J. Clin. Nutr. 2014; 100: 746–755.
26. Holick MF, Chen TC, Lu Z, Sauter E. Vitamin D and skin physiology: a D-lightful story. J Bone Miner Res. 2007; 22:28–33.
27. Lesa KN, Khandaker MU, Mohammad Rashed Iqbal F, Sharma R, Islam F, Mitra S, Emran TB. Nutritional value, medicinal importance, and health-promoting effects of dietary mushroom (Pleurotus ostreatus). Journal of Food Quality. 2022.
28. Waktola G, Temesgen T. Pharmacological activities of Oyster mushroom (Pleurotus ostreatus). Novel Research in Microbiology Journal. 2020 ;4(2):688-95.
29. Gupta KK, Agarwal S, Kushwaha A, Maurya S, Chaturvedi VK, Pathak RK, Verma V, Singh MP. Oyster mushroom: A rich source of antioxidants. Incredible World of Biotechnology. 2017; 1:43-57.
30. Ullah Z, Ali U, Ali S, Ali A, Alam N, Sher H. Medicinal Flora and Cultural Values of Arkot-Biakand Valley Hindu Kush Region Swat, Pakistan. Ethnobiology of Mountain Communities in Asia. 2021;327-80.
31. Venturella G, Ferraro V, Cirlincione F, Gargano ML. Medicinal mushrooms: bioactive compounds, use, and clinical trials. International journal of molecular sciences. 2021;22(2):634.
32. Hassan MA, Rouf R, Tiralongo E, May TW, Tiralongo J. Mushroom lectins: specificity, structure and bioactivity relevant to human disease. International journal of molecular sciences. 2015 ;16(4):7802-38.
33. Coelho LC, Silva PM, Lima VL, Pontual EV, Paiva PM, Napoleao TH, Correia MT. Lectins, interconnecting proteins with biotechnological/pharmacological and therapeutic applications. Evidence-Based Complementary and Alternative Medicine. 2017.
34. Paudel N, Rai M, Adhikari S, Thapa A, Bharati S, Maharjan B, Shrestha RL, Rav K, Singh AV. Green Extraction, Phytochemical Profiling, and Biological Evaluation of Dysphania ambrosioides: An In Silico and In Vitro Medicinal Investigation. Journal of Herbs, Spices & Medicinal Plants. 2023 Oct 16:1-8.
35. Margulis L, Chapman M.J. Kingdoms and Domains: An Illustrated Guide to the Phyla of Life on Earth; Academic Press: Cambridge, MA, USA. 2010.
36. Weete J.D, Abril M, Blackwell M. Phylogenetic distribution of fungal sterols. Plos one. 2010;5: e10899.
37. Keegan R.J, Lu Z, Bogusz J.M, Williams J.E, Holick M.F. Photobiology of vitamin D in mushrooms and its bioavailability in humans. Dermatoendocrinology. 2013; 5: 165–176.
38. Jasinghe V.J, Perera C.O, Sablini S.S. Kinetics of the conversion of ergosterol in edible mushrooms. J. Food Eng. 2007; 79: 864–869.
39. Phillips K.M, Horst R.L, Koszewski N.J, Simon R.R. Vitamin D4 in mushrooms. Plos one. 2012; 7: e40702.
40. Cheung PC. The nutritional and health benefits of mushrooms. Nutr Bull. 2010; 35:292.
41. Kamweru PK, Tindibale EL. Vitamin D and vitamin D from ultraviolet-irradiated mushrooms. International Journal of Medicinal Mushrooms. 2016;18(3).
42. Yokokawa H, Mitsuhashi T. The sterol composition of mushrooms. J Photochem. 1981; 20:1349–51.
43. Mattila PH, Lampi AM, Ronkainen R, Toivo J, Piironen V. Sterol and vitamin D2 contents in some wild and cultivated mushrooms. Food Chem. 2002; 76:293–8.

44. Roy M. K, Juneja L. R & Isobe S. Changes in the sensory characteristics of shiitake mushrooms treated with UV-B light. Journal of Food Science.2006; 71(8): S568-S574.
45. Li X, Zhao J, Ma X & Liu C. Enhanced production of exopolysaccharides by UV-irradiation in submerged culture of Grifola frondosa and its immuno-stimulating activity. International Journal of Biological Macromolecules.2018; 112: 778-784.
46. Fukushima M, Nakano M, Morii Y, Ohashi T, Fujiwara Y, Sonoyama K. Hepatic LDL receptor mRNA in rats is increased by dietary mushroom (Agaricus bisporus) fiber and sugar beet fiber. The Journal of nutrition. 2000 ;130(9):2151-6.
47. Dan X, Liu W, Ng TB. Development and applications of lectins as biological tools in biomedical research. Medicinal research reviews. 2016;36(2):221-47
48. Lull C, Wichers HJ, Savelkoul HF. Antiinflammatory and immunomodulating properties of fungal metabolites. Mediators of inflammation. 2005 Jun 9; 2005:63-80.
49. Zhao S, Gao Q, Rong C, Wang S, Zhao Z, Liu Y, Xu J. Immunomodulatory effects of edible and medicinal mushrooms and their bioactive immunoregulatory products. Journal of Fungi. 2020 ;6(4):269.
50. Liu Y, Bastiaan-Net S, Wichers HJ. Current understanding of the structure and function of fungal immunomodulatory proteins. Frontiers in Nutrition. 2020 ; 7:132.
51. Gupta S, Summuna B, Gupta M, Annepu SK. Edible mushrooms: cultivation, bioactive molecules, and health benefits. Bioactive molecules in food. 2018; 1:1-33.
52. Wang H, Gao J, Ng TB. A new lectin with highly potent antihepatoma and antisarcoma activities from the oyster mushroom Pleurotus ostreatus. Biochemical and biophysical research communications. 2000;275(3):810-6.
53. Mirunalini s, arulmozhi v, deepalakshmi k, krishnaveni m. Intracellular biosynthesis and antibacterial activity of silver nanoparticles using edible mushrooms. Notulae Scientia Biologicae. 2012;4(4):55-61.
54. Deepalakshmi K, Sankaran M. Pleurotus ostreatus: an oyster mushroom with nutritional and medicinal properties. Journal of Biochemical Technology. 2014;5(2):718-26.
55. El Enshasy HA, Hatti-Kaul R. Mushroom immunomodulators: unique molecules with unlimited applications. Trends in biotechnology. 2013;31(12):668-77.
56. Wu JY, Chen CH, Chang WH, Chung KT, Liu YW, Lu FJ, Chen CH. Anti-cancer effects of protein extracts from Calvatia lilacina, Pleurotus ostreatus and Volvariella volvacea. Evidence-Based Complementary and Alternative Medicine. 2011.
57. Adebayo EA, Oloke JK, Aina DA, Bora TC. Antioxidant and nutritional importance of some Pleurotus species. Journal of microbiology, biotechnology and food sciences. 2014;3(4):289-94.
58. Hapsari R, Elya B, Amin J. Formulation and evaluation of antioxidant and tyrosinase inhibitory effect from gel containing the 70% ethanolic Pleurotus ostreatus extract.
59. Zhang Y, Dai L, Kong X, Chen L. Characterization and in vitro antioxidant activities of polysaccharides from Pleurotus ostreatus. International journal of biological macromolecules. 2012 ;51(3):259-65.
60. Elhusseiny SM, El-Mahdy TS, Awad MF, Elleboudy NS, Farag MM, Yassein MA, Aboshanab KM. Proteome analysis and in vitro antiviral, anticancer and antioxidant capacities of the aqueous extracts of Lentinula edodes and Pleurotus ostreatus edible mushrooms. Molecules. 2021;26(15):4623.
61. Espinosa-Paez E, Hernandez-Luna CE, Longoria-García S, Martinez-Silva PA, Ortiz-Rodríguez I, Villarreal-Vera MT, Cantú-Saldaña CM. Pleurotus ostreatus: A potential concurrent biotransformation agent/ingredient on development of functional foods (cookies). Lwt. 2021; 148:111727.
62. B. A. Iwalokun, U. A. Usen, A. A. Otunba , “Comparative phytochemical evaluation, antimicrobial and antioxidant properties of Pleurotus ostreatus,” African Journal of Biotechnology.2007; 6(15): 1732–1739.

63. Younis A.M, Wu F.S, El-Shikh H H. Antimicrobial activity of extracts of the oyster culinary medicinal mushroom Pleurotus ostreatus (Higher Basidiomycetes) and identification of a new antimicrobial compound. International Journal of Medicinal Mushroom.2015; 17(6): 579-585.
64. Mone NS, Syed S, Ravichandiran P, Kamble EE, Pardesi KR, Salunke-Gawali S, Rai M, Vikram Singh A, Prasad Dakua S, Park BH, Yoo DJ. Synergistic and Additive Effects of Menadione in Combination with Antibiotics on Multidrug-Resistant Staphylococcus aureus: Insights from Structure-Function Analysis of Naphthoquinones. ChemMedChem. 2023 Dec 14;18(24):e202300328.
65. Choudhury MB, Rahman T, Kakon AJ, Hoque N, Akhtaruzzaman M, Begum MM, Choudhuri MS, Hossain MS. Effects of Pleurotus ostreatus on blood pressure and glycemic status of hypertensive diabetic male volunteers. Bangladesh Journal of Medical Biochemistry. 2013;6(1):5-10.
66. Karaman M, Jovin E, Malbaša R, Matavuly M, Popović M. Medicinal and edible lignicolous fungi as natural sources of antioxidative and antibacterial agents. Phytotherapy research. 2010;23(10):1473-81.
67. Antioxidant antimicrobial potential and element levels of Laccaria laccata. 2022;31(9):9621-6.
68. Titilawo MA, Faseun AO, Akinde SB, Olaitan JO, Odeyemi O. Bioactivity of Four Nigerian Wild Mushrooms against Some Typed Clinical Isolates. Jordan Journal of Biological Sciences. 2022;15(1).
69. Martins T, Machado-Carvalho L, Aires A, Saavedra MJ, Marques G. Antioxidant, Antimicrobial and Cosmeceutical Potential of Wild Mushroom Extracts. Applied Microbiology. 2023 ;3(2):562-79.
70. Kalu AU, Chinenye OA, Lydia EA, Jude OU. In vitro antimicrobial activity of Armillaria mellea against pathogenic organisms. Int J Biotech Microbiol. 2022;4(1):39-44.
71. Bal C, Eraslan EC, Sevindik M. Antioxidant, Antimicrobial Activities, Total Phenolic and Element Contents of Wild Edible Mushroom Bovista nigrescens. Prospects in Pharmaceutical Sciences. 2023;21(2):37-41.
72. Xu J, Xu D, Hu Q, Ma N, Pei F, Su A, Ma G. Immune regulatory functions of biologically active proteins from edible fungi. Frontiers in Immunology. 2023;13:1034545.
73. Mishra A, Behura A, Mawatwal S, Kumar A, Naik L, Mohanty SS, Manna D, Dokania P, Mishra A, Patra SK, Dhiman R. Structure-function and application of plant lectins in disease biology and immunity. Food and Chemical Toxicology. 2019; 134:110827.
74. Arunachalam K, Sasidharan SP, Yang X. A concise review of mushrooms antiviral and immunomodulatory properties that may combat against COVID-19. Food Chemistry Advances. 2022;1:100023.
75. Abbas HS, Kotakonda M. Lectins Are the Sparkle of Hope for Combating Coronaviruses and the Global COVID-19. Advanced Pharmaceutical Bulletin. 2022;12(2):319.
76. Balique F, Colson P, Barry AO, Nappez C, Ferretti A, Moussawi KA, Ngounga T, Lepidi H, Ghigo E, Mege JL, Lecoq H. Tobacco mosaic virus in the lungs of mice following intra-tracheal inoculation. PLoS One. 2013;8(1):e54993.
77. Islam F, Azad AK, Faysal M, Islam S, Sugandha NJ, Saha S, Isah SI. Phytochemical investigation and comparative anthelmintic activity of between methanol and acetone extract of limonia acidissima l (fruit peel). Pharmacologyonline.2019 ;2:241-6.
78. M EL-Fakharany E, M Haroun B, Ng T, M Redwan ER. Oyster mushroom laccase inhibits hepatitis C virus entry into peripheral blood cells and hepatoma cells. Protein and peptide letters. 2010;17(8):1031-9.
79. Kumar K, Mehra R, Guiné RP, Lima MJ, Kumar N, Kaushik R, Ahmed N, Yadav AN, Kumar H. Edible mushrooms: A comprehensive review on bioactive compounds with health benefits and processing aspects. Foods. 2021;10(12):2996.
80. Yoshioka Y, Ikekawa T, Noda M, Fukuoka F. Studies on antitumor activity of some fractions from basidiomyces. I. An antitumor acidic polysaccharide fraction of P. Ostreatus (Fr.)

Quel. Chemical and Pharmaceutical Bulletin. 1972 ;20(6):1175-80.

81. Martin KR, Brophy SK. Commonly consumed and specialty dietary mushrooms reduce cellular proliferation in MCF-7 human breast cancer cells. Experimental biology and medicine. 2010;235(11):1306-14.
82. Galappaththi MC, Dauner L, Madawala S, Karunarathna SC. Nutritional and medicinal benefits of oyster (Pleurotus) mushrooms: a review. Fungal Biotec. 2021;1(2):65-87.
83. Pandey AT, Pandey I, Hachenberger Y, Krause BC, Haidar R, Laux P, Luch A, Singh MP, Singh AV. Emerging paradigm against global antimicrobial resistance via bioprospecting of mushroom into novel nanotherapeutics development. Trends in Food Science & Technology. 2020; 106:333-44.
84. Lesa KN, Khandaker MU, Mohammad Rashed Iqbal F, Sharma R, Islam F, Mitra S, Emran TB. Nutritional value, medicinal importance, and health-promoting effects of dietary mushroom (Pleurotus ostreatus). Journal of Food Quality. 2022.
85. Gil-Ramirez A, Smiderle FR, Morales D, Govers C, Synytsya A, Wichers HJ, Iacomini M, Soler-Rivas C. Water-soluble polysaccharide extracts from the oyster culinary-medicinal mushroom Pleurotus ostreatus (Agaricomycetes) with HMGCR inhibitory activity. International Journal of Medicinal Mushrooms. 2017;19(10).
86. Vetvicka V, Vetvickova J. Immune-enhancing effects of Maitake (Grifola frondosa) and Shiitake (Lentinula edodes) extracts. Ann Transl Med, 2020, 8(19):1254. doi: 10.21037/atm-20-3922.
87. Wasser SP Medicinal mushroom science: Current perspectives, advances, evidences, and challenges. Biomed J, 2017, 40(1):1-2. doi: 10.1016/j.bj.2017.02.002.