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Mushroom as source of medicinal food items: A review

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Abstract
Since immunity and cellular protection is important concern for people who are very much health-conscious, and also for those managing serious health issues, mushrooms have been prized worldwide because of their nutritional and medicinal qualities. Vegans are now more interested in eating mushrooms than ever before. Research studies indicate that mushrooms containing a notable quantity of complex polysaccharides have the greatest potential to improve human health, inhibit cancer growth and modulate immune responses. Because of protein rich source, mushrooms are being used in both nutraceuticals and medicines. Proteins in mushrooms with ribonuclease, lectin, antibacterial, ribosome inactivating and fungal immunomodulatory functions exhibit interesting biological activities. Due to the presence of numerous bioactive components in significant amount, mushrooms have now gained more approval as a food and nutritional supplements, which are known to have over 126 health benefits other than their antibacterial, immunomodulating, antiviral and hypocholesterolemic properties. Most of the edible mushrooms have polyunsaturated fatty acids, expressing that they efficiently lower down the serum cholesterol too. Ergosterol found in edible mushroom may be the source of antioxidant activities. Worldwide, the research is still being done on nutritional and therapeutic properties of different mushrooms.

Keywords: Immunomodulating, nutritional, properties

Introduction
Majority of the people on the planet believe that mushroom is very tasty and nutritious food. Previous research clearly demonstrates that the olfactory appeal of these delightful macro-organisms was employed to tempt the Roman nobilities. Additionally, a variety of these macro-organisms were thought to be excellent photographic subjects by the photographers (Hall *et al*., 2003) [40]. The Greeks presumed that mushrooms would give them vigor in battles, while the Chinese considered mushroom as a healthy food or an Elixir of Life (Valverde *et al*., 2015) [102]. Because of their abilities to support human health, several mushroom powders or extracts are sold as nutritional supplements (Chugh *et al*., 2022; Venturella *et al*., 2021) [22, 104]. There are around 1600 species of mushroom on the planet, however, only 100 species have been recognized edible till now. Approximately 33 edible varieties of mushrooms are grown worldwide, however, only three are widely cultivated, *viz.* oyster (*Pleurotus ostreatus* L.), white button (*Agaricus bisporus* L.) and paddy straw (*Volvariella volvacea* L.) mushroom (Erbiai *et al.*, 2021) [29]. The most common application of edible mushrooms is to prepare nutraceuticals and medications with antioxidant, antibacterial and anticancer properties. Mushrooms though have medicinal significance, their high protein, low fat and low energy content make them vibrant to human nutrition (Khatun *et al.*, 2012) [56]. As per the FAOSTAT database, the production of mushrooms increased worldwide from 7.5 million tonnes in 2009 to 11.8 million tonnes in 2019 (Bringye *et al*., 2021) [14]. Mushrooms have been considered as a functional or designer food and a source of nutraceuticals due to their positive benefits on human health, which derive from their bioactive compounds and nutraceutical components (Valverde *et al*., 2015) [102].

Nutritional Analysis
1. Carbohydrates availability in mushroom
Owing to their anticancer and immunomodulatory qualities, mushrooms containing a notable quantity of complex polysaccharides are pharmacologically highly relevant.

Common carbohydrates found in different mushrooms that have been shown to have significant biological effects on human health include fucose, xylose, rhamnose, fructose, mannose, glucose, mannitol, maltose, sucrose and trehalose (Ferreira *et al.*, 2009; Zaidman *et al.*, 2005; Alves *et al.*, 2013; Zhang *et al.*, 2007) [33, 117, 6, 118]. The fruiting bodies of mushrooms contain 50-65% of carbohydrates on dry weight basis, which are made up of sugars (Monosaccharides) and their derivatives (Oligosaccharides). A little quantity of alcoholic sugars, such as trehalose and mannitol, is also present in the carbohydrates. When exposed to environmental conditions such as heat, cold, desiccation, oxidation, *etc*., trehalose is known to manufacture stress-responsive factors in human cells while maintaining cellular integrity. One potential explanation for this could be the avoidance of protein denaturation, which often breaks under stressful situations (Jain and Roy, 2009) [47]. The polysaccharides found in mushrooms that have anticancer activity react either acidically or neutrally, and their chemical structures differ markedly from one another. Glycans such as homopolymers or extremely complex heteropolymers show antitumor activity. Mushrooms do not kill the tumor cells directly though the polysaccharides present in them modulate the host immune response by activating it. These substances reduce stress on human body and exhibit a roughly 50% reduction in tumor size, which prolongs the survival period of the tumor-bearing mice. (Wasser, 2002; Synytsya *et al.*, 2008) [109, 100]. Oyster mushrooms are unquestionably an excellent source of nutritional fiber and carbohydrates. The predominant polysaccharides found in mushrooms include chitin, α- and β-glucans, as well as various hemicelluloses, such as xylans, mannans and galactans (Alam *et al.*, 2008) [3]. *Pleurotus species* contain a particular type of glucan known as pleuran, which exhibits anticancer effects. Though it varies from species to species, the amount of dietary fiber and polysaccharides in dry fruit bodies ranges from 10 to 31 and 36 to 60 g/100 g, respectively (Khan *et al.*, 2008; Mshandete and Cuff, 2007; Dundar *et al.*, 2008; Gbolagade *et al.*, 2006; Klis *et al.*, 2001) [54, 76, 28, 39, 59]. Majority of the β-glucans in cell wall of the mushrooms are highly valuable for industrial applications because they are excreted in the cell growth media, making it simpler to recover, purify and chemically characterize them (Klis *et al.*, 2001; McIntosh *et al.*, 2005; Schmid *et al.*, 2001) [29, 73, 92]. This constituent possesses the ability to bind membrane receptors and activate biological responses, including immune system stimulation and is also responsible for anticholesterolemic, antioxidant, immunomodulating and neuroprotective effects (Falch *et al.*, 2000; Ishibashi *et al.*, 2001; Kataoka *et al.*, 2002; Khan *et al.*, 2013) [31, 45, 51, 55].

2. Protein availability in mushroom

As mushrooms are an excellent source of protein, they are utilized in both medicines and nutraceuticals. Proteins with intriguing biological properties include ribonucleases, lectins, ribosome-inactivating, antimicrobial, fungal immunomodulatory and laccases (Xu *et al.*, 2011) [14]. Despite variations in protein content among species and strains, maturity stages, growth substrates, and environmental conditions, mushrooms offer a substantial amount of protein at a relatively cheaper cost when compared with protein from plant and animal sources (Kaur *et al.*, 2022) [52]. Protein-rich mushrooms contain all the essential amino acids, with aspartic acid, glutamic acid and arginine being particularly abundant. In addition, mushrooms have also been shown to contain two uncommon amino acids, *viz.* (i) ornithine, which is known for its peculiar physiological activity, and (ii) γ-amino butyric acid (GABA), which is a non-essential amino acid (Manzi *et al.*, 1999) [71]. Consuming that protein makes up about 17% of the overall number of calories essentially needed by the human body (Floret *et al.*, 2021) [34]. Lectins are non-immune or glycol proteins that adhere to the cell surface of carbohydrates. Several lectins have been discovered over the last few years (Singh *et al.*, 2010) [96]. Yet again, oyster mushrooms (*Pleurotus* spp.) serve as a source of valuable protein. Studies carried out globally in different institutions have already demonstrated that variables such as the species' genetic makeup, variations in the growing medium's chemical and physical properties, the substrates' composition and the timings of harvesting all affect the protein content in mushrooms (Mshandete *et al.*, 2007) [76]. The powder form of *Lentinus squarrosulus* showed a very good protein value, *i.e.*, 30.12 g/100 g dry body weight (Ayimbila *et al.*, 2022) [7]. According to studies on different species of *Pleurotus*, the average protein content of dried fruit bodies ranges from 11 to 42 g/100 g dry body weight. Because oyster mushrooms contain both essential and non-essential amino acids, they are of higher quality (Dundar *et al.*, 2008; Akindahunsi and Oyetayo, 2006; Patil *et al.*, 2010; Oyetayo *et al.*, 2007) [28, 2, 84, 82]. The most popular edible mushroom species, such as *Agaricus bisporus*, *Lentinus edodes* and *Pleurotus ostreatus* contained protein 14.87 to 27.13 (Li *et al.*, 2022) [67], 26.60 to 39.84 (Krishnamoorthi *et al.*, 2022) [63] and 18 to 19.15% (Dilfy *et al.*, 2020) [25], respectively. An innovative class of bioactive proteins called fungal immunomodulatory proteins shows potential for use as an adjuvant in tumor immunotherapy (Lin *et al.*, 2010) [68]. It has been observed that some edible mushrooms have more protein than cereals, fruits and vegetables (Yu *et al.*, 2020) [116].

3. Lipids availability in mushroom

Since polyunsaturated fatty acids are present in majority of the edible mushrooms, they efficiently lower serum cholesterol. Ergosterol is a sterol found in edible mushrooms, having antioxidant properties. Studies have indicated that eating a diet high in sterols can help in preventing heart diseases (Barros *et al.*, 2007; Kalac, 2013) [10, 50]. To maintain proper lipid homeostasis, dietary fat is essential since it is considered a significant part of a typical diet and a tight feedback regulator. In general, mushrooms have a low lipid content. Since fresh mushrooms have a higher water content than dried ones, the lipid proportion in fresh mushrooms of various species ranges from 1.75 to 15.5% (Hong *et al.*, 1988) [43]. Mushrooms contain tocopherols, which are naturally occurring antioxidants. The substances that exhibit antioxidant action also exhibit other biological activities, including the protection against cancer, cardiovascular disease and degenerative disorders. Additionally, linoleic acid, which is abundant in mushrooms and has a wide range of physiological effects such as lowering blood pressure, triglycerides, arthritis and cardiovascular disorders, is an important fatty acid for humans (Ferreira *et al.*, 2009; Alves *et al.*, 2013; Puttaraju *et al.*, 2006; Reis *et al.*, 2012) [33, 6, 86, 90]. Multiple studies have analyzed the fatty acid composition of different types of mushrooms and clarified the nutritional value of these food items for human diets (Wang *et al.*, 2001) [106]. Barros *et al.* (2007) [11] reported that linoleic and oleic acid are the main fatty acids found in *Lactarius deliciosus*, *Agaricus arvensis*, *Sarcodon imbricatus*, *Leucopaxillus giganteus* and *Tricholoma portentosum*. Hossain *et al.* (2007)

[44] reported that together with other two essential fatty acids, arachidonic acid (10.8 µg/g of dry body weight) and linolenic acid (11.6 µg), oyster mushrooms also include linoleic acid (533 µg) and oleic acid (363 µg). *Pleurotus sajor-caju* has odd carbon fatty acids including pentadecanoic acid but the other oyster (*Pleurotus florida*) mushrooms have main fatty acids like linoleic and palmitic acids (Kavishree *et al.*, 2008) [53]. The lipid content of mushrooms is significantly influenced by several factors, including growth conditions, nutrition, oxygen and temperature (Pedneault *et al.*, 2007) [85]. The lipid content of various species of *Pleurotus* fruit bodies typically varies between 0.2 and 8 g/100 g of dry body weight (Fasidi *et al.*, 1993) [32].

4. Minerals availability in mushroom

Based on data from prior studies, most of the mushrooms' fruiting bodies have a high concentration of minerals such as potassium, phosphorus, sodium, zinc and iron, however, *Pleurotus* mushrooms have been found to have considerable amount of iron, zinc, calcium, magnesium, manganese, copper, phosphorus and potassium (Dillard *et al.*, 2000) [26], therefore, one should include mushrooms in his or her diet to prevent deficits of trace elements like iron, zinc and other micronutrients. Depending on species, the individual mushroom has different mineral content. This discrepancy could result from different nutrient sources being used for cultivation as well as different methods being used to determine the minerals (Khan *et al.*, 2013) [55].

Nutraceutical Composition in mushroom

The most common application for edible mushrooms is in the preparation of nutraceuticals and medications with antibacterial, antioxidant and anticancer properties. Because of their high protein, low fat and low energy content, mushrooms are important for human diets in addition to their medicinal values (Khatun *et al.*, 2012) [56]. Nutraceuticals, often known as functional, medicinal, or designer foods, are goods that include phytochemicals. Nutraceuticals made of fungal mycelium or fruit bodies grown in submerged culture that are used as dietary supplements in the form of capsules, pills, tonics, or powders that contain compounds that are nutritious as well as health-promoting (Chang and Buswell, 1996) [16]. The proteins found in mushrooms include every important amino acid required by the human body. In addition, mushrooms contain a wide range of nutrients, including iron, phosphorus and vitamins like ergosterol, riboflavin, niacin and ascorbic acid (Kumar, 2015) [65]. The well-known medicinal mushrooms, *i.e.*, *Agaricus subrufescens*, *Ganoderma lucidum* and *Ophiocordyceps sinensis*, are among those with a long history of use. These fungi produce chemicals that have been found to have biological inhibitory actions against viruses and cancerous cells. Clinical medicines frequently make use of certain metabolites, including polysaccharide-K, ergotamine and beta-lactam antibiotics (Chugh *et al*., 2022; Sanchez and Demain, 2017) [22, 91]. They are applied for the management of persistent hepatitis. They are helpful in boosting vitality, sharpening the mind and avoiding amnesia. *Ganoderma lucidum*-derived extracts and powders are sold as medicines just like pills with sugar coatings or capsules for a variety of illnesses (Wang *et al*., 2018) [107]. Additionally, the hypocholesterolemic, hypoglycemic and hypolipidemic properties of *Pleurotus ostreatus* have been documented. Mushrooms have powerful pharmacological or physiological characteristics, including bioregulation (Immunological augmentation), homeostasis maintenance, biorhythm regulation, therapy of a wide range of ailments, and the avoidance and amelioration of life-threatening conditions like cancer, stroke, cardiac problems, immune system disorders (Including AIDS), or the development of immunosuppression while receiving medication (Alam *et al*., 2011) [4].

Bioactive compounds in Edible Mushrooms

Numerous bioactive components, such as polysaccharides, lectins, glucans, terpenoids and phenolics are produced by mushrooms and are known to have over 126 health benefits, including antiviral, antioxidant, immunomodulatory, antibacterial and hypocholesterolemic properties (Badalyan, 2014) [8]. Medicinal mushrooms, of which a large number are wood-dwelling species like polypore mushrooms, serve as an excellent natural source of bioactive components that may be specifically beneficial to maintain human health and prevent different disease states. These bioactive components may express a variety of pharmacological effects, including those that are antioxidative, hepatoprotective, immunomodulatory, antibacterial, anticancer and antidiabetic (Fogarasi *et al.*, 2018; Reis *et al.*, 2017; Garofalo *et al.*, 2017; Fogarasi *et al.*, 2020) [36, 89, 38, 35]. The proteins such as hydrophobins, lectins, proteases, ribosome-inactivating and enzymes that degrade lignocellulose, found in various types of mushrooms possess many biological properties. These proteins have a great deal of potential for use in various biotechnological applications, such as the creation of new drugs (Erjavec *et al.*, 2012) [30]. The mushroom species, *i.e.*, *Armillaria mellea*, from Northern Morocco possesses highest antioxidant capacity. Cinnamic acid (155.20±0.97 µg/g of dry body weight) and vanillic acid (198.40 µg/g of dry body weight) were the primary compounds found in *Armillaria mellea* samples, according to LC-MS analysis of individual phenolic compounds. Protocatechuic acid (92.52 and 125.50 µg/g of dry body weight) predominated in *Macrolepiota procera* samples from Northern Morocco and Portugal, respectively. It has been discovered that the extracts from medicinal mushrooms with cytotoxic steroids and various polypeptide types, such as *Polyporus umbellatus* and *Polyporus alveolaris*, have hepatoprotective, immunostimulating, antibacterial, anticancer and anti-inflammatory properties (Jiang and Sliva, 2010) [48]. The anticarcinogenic, antiviral, antiarthritic, hypocholesterolemic, antioxidant, antibacterial, antidiabetic and hepatoprotective properties of oyster mushrooms (*Pleurotus species*) are well-known. These edible mushrooms can help people who are protein deficient, especially in impoverished nations where animal proteins are not acceptable owing to religious responsibilities (Kumar *et al.*, 2020) [66].

Mushroom's bioactive compounds for good health

Owing to the high concentration of bioactive compounds, edible mushrooms have a wide range of medicinal uses. In fighting various lifestyle disorders, including diabetes, liver disorders, cancer and cardiovascular disease, these are thought to be quite helpful (Kumar *et al.*, 2014) [64]. The following subheadings explain the various health benefits of edible mushrooms:

1. Anticarcinogenic properties

Medicinal mushrooms are rich in bioactive compounds that may have anticancer effects. These substances include dietary fiber, polysaccharide complexes, certain protein types, terpenoids, phenolics and steroids. Daba and Ezeronye (2003)

[23] investigated the anticancer effect of fruit bodies and mycelial extracts of mushrooms using a variety of malignant cell lines. Sarcoma 180, mammary adenocarcinoma 755, leukemia L-1210 and other tumors were all susceptible to the anticancer effects of polysaccharides derived from mushrooms. Baker *et al*. (2008) [9] found *Phellinus linteus* to have immune-modulating, anti-metastasis and anticancer properties. Patel and Goyal (2012) [83] revealed that the genus *Phellinus*, *Cordyceps*, *Agaricus*, *Fomes*, *Albatrellus*, *Trametes*, *Pleurotus*, *Xerocomus*, *Russula*, *Clitocybe*, *Calvatia*, *Schizophyllum*, *Flammulina*, *Ganoderma*, *Inonotus*, *Antrodia*, *Suillus*, *Lactarius*, *Inocybe* and *Funlia* are the ones with anticarcinogenic properties. Shin *et al*. (2010) [95] revealed that how eating mushrooms in Korea lowered the breast cancer risk in 358 women and 360 cancer-free (Control) women. They also found that premenopausal women who consumed more mushrooms had a lower risk of developing breast cancer, and that this association may be stronger in women who had hormone receptor-positive tumors.

2. Antioxidative properties

The antioxidant compounds found in various food types possess the ability to entangle free radicals and suppress the oxidative modifications that result in different degenerative illnesses (Mehra *et al.*, 2020) [71]. Fruits, whole grains, vegetables, spices, tea, herbs, as well as veggies all contain natural antioxidants. Mushrooms have also been characterized as a significant source of antioxidants because of their phenolic components and other polysaccharides (Dubost *et al.*, 2007; Mau *et al.*, 2005; Wei *et al.*, 2008) [27, 72, 112]. By boosting antioxidant defense, adding edible mushrooms to the diet can lower oxidative stress. Wild or cultivated mushrooms possess significant antioxidant properties, primarily because they contain bioactive substances like carotenoids, polyphenolics, polysaccharides and vitamins. Since they contain health-promoting substances, edible mushrooms are frequently used as a delicate food (Kozarski *et al.*, 2015) [62]. Liu *et al*. (1997) [69] proved that the polysaccharides found in the cell walls of mushrooms bears a strong antioxidant capacity by *in vitro* scavenging of free radicals.

3. Hypocholesterolemic agents

Hypercholesterolemia, low-density lipophilic oxidation and atherosclerosis correspond to heart diseases. Thus, it is crucial to regulate blood cholesterol levels in order to prevent and treat diseases. Due to their low-fat and high fiber content, edible mushrooms are the best meal to avoid heart ailments. Oriental medical practitioners frequently advise to include more edible mushrooms in a natural hypocholesteromic and antisclerotic diet (Ishikawa *et al.*, 1986) [46]. A high fiber content in mushrooms may help in lowering total serum cholesterol, triglycerides and low-density lipoprotein (LDL). It has been shown that using *Termitomyces microcarpus* mushrooms has greatly reduced the prevalence of disorders connected to high blood lipids (Nabubuya *et al.*, 2010) [77]. The submerged cultures of *Flammulina velutipes*, *Hericium erinaceus*, *Phellinus pini*, *Auricularia auricula-judae*, and *Grifola frondosa* (GF) produce exo-polymers that cause hypolipidemia in the test animals (Yang *et al.*, 2002) [115]. Rathee *et al*. (2012) [87] isolated and recognized Eeritadenine [2(R) 3(R)-dihydroxy-4(9-adenyl)-butyric acid], an active hypocholesterolemic substance, is found in shiitake mushrooms.

4. Hepatoprotective effects

Oxidative stress is the primary cause of liver damage, which manifests as cirrhosis, fibrosis, chronic hepatitis and hepatocellular cancer (Kodavanti *et al.*, 1989) [60]. Hepatotoxicity is an ailment that results in reduced liver function and can be brought on by ingesting any medication or other non-infectious substances (Navarro *et al.*, 2006) [79]. Similarly, it was found that an ethanolic extract from *Calocybe indica* mushroom protected humans against hepatotoxicity induced by carbon tetra chloride poisoning in rats by preventing liver injury (Chatterjee *et al.*, 2011) [17]. When tested by using galactosamine-induced cytotoxic test, ganoderic acid R and S and ganopsoreric acid A from *Ganoderma lucidum* mushrooms showed anti-hepatotoxic properties *in vitro* in primary cultured rat hepatocytes (Hirotani *et al.*, 1986) [41]. *Hericium erinaceus* polysaccharides can be taken as a supplement to help in avoiding several liver diseases (Zhang *et al.*, 2012) [119]. The extract from basidiomass of *Lentinus edodes* and *Ganoderma frondosa* (100 mg/kg of body weight) was found to be highly effective in reducing the proliferation of aspartate transaminase and alanine transaminase levels induced by paracetamol, the mycelial aqueous extract from *Tricholoma lobayense* mushroom demonstrated hepatoprotective effects at higher doses of 300 mg/kg of body weight (Ooi *et al.*, 1996) [81]. *Agaricus blazei* extract has demonstrated comparable efficacy in preventing liver damage caused by paracetamol (Soares *et al.*, 2013) [97]. Sumy *et al*. (2014) [99] examined the hepatoprotective properties of *Pleurotus florida* mushroom against albino rats' injuries brought on by paracetamol consumption. The ethanolic extract from the mycelium of *Morchella esculenta* was discovered to have significant antioxidant and hepatoprotective properties based on the experimental results. The polysaccharide-rich extract from *Pleurotus eryngii* is a valuable functional food additive because it has been demonstrated to have hepatoprotective and hypolipidemic effects (Chen *et al.*, 2012) [18].

5. Antidiabetic effects: Diabetes mellitus is a metabolic disorder that can be controlled with increased physical activity, eating a balanced diet and living under stress free conditions. As a functional food, mushrooms can help in controlling diabetes mellitus. These are a great source of bioactive chemicals that have anti-diabetic properties. A variety of mushrooms are excellent for controlling sugar levels in blood stream and the problems brought on by diabetes. Numerous research studies have shown that mushrooms have hypoglycemic properties, including *Agaricus bisporus*, *Agaricus subrufescens*, *Ganoderma lucidum*, *Coprinus comatus*, *Inonotus obliquus*, *Pleurotus* spp., *Poria cocos*, *Phellinus linteus*, *Cordyceps sinensis* and *Sparassis crispa* (De-Silva *et al.*, 2012) [24]. Because edible mushrooms are very low in fat, cholesterol and carbohydrates and abundant in protein, vitamins and minerals, they are considered a low-calorie meal for diabetics (De-Silva *et al.*, 2012) [24]. In mushrooms, beta-glucan is a polysaccharide, which is widely distributed. It has been discovered to restore pancreatic tissues by augmenting the release of insulin by β-cells, resulting in a reduction of glucose levels in blood. *Agaricus bisporus* and *Agaricus campestris* lectins were found to increase the hormone insulin release from islets of Langerhans in rat pancreatic tissues (Ahmad *et al.*, 1984) [1]. The level of serum glucose of alloxan-induced diabetic mice was significantly reduced by the ethanolic extract of *Pleurotus ostreatus* mushroom. In the post-treatment groups,

there was a significant decrease in the levels of urea and creatinine in the serum. *Pleurotus ostreatus* mushrooms have been discovered to be useful in medicinal compositions for treating diabetes mellitus (Ravi *et al.*, 2013) [88].

6. Antimicrobial effects

With exceptional therapeutic benefits, mushroom is regarded as the best dietary supplements. Antimicrobial properties of some edible mushrooms help in managing a range of illnesses in humans. Against hardy disease-causing microorganisms, they were found to possess antifungal and antibacterial properties (Sharma *et al.*, 2014) [93]. The existence of phenolic compounds in *Inonotus hispidus* mushrooms and ergosterol peroxide in a range of mushrooms has been linked to *in vitro* antiviral effects against influenza viruses (Ali *et al.*, 2003) [5]. Chowdhury *et al*. (2015) [21] shown antibacterial properties in a few Bangladeshi edible mushroom types. The range of inhibition zone against all fungi and bacteria was 7 to 20 mm. When compared with other mushroom types, *Lentinula edodes* was found to have the best antibacterial activity. *Saccharomyces cerevisiae* was more vulnerable than other microbiological isolates, although *Pleurotus aeruginosa* was a somewhat resistant fungus. Chen and Huang (2010) [19] examined the culture filtrates of 27 edible mushrooms for antibacterial properties and discovered that the filtrates of *Clitocybe nuda* and *Lentinula edodes* were successful in stopping *Colletotrichum higginsianum* spores from germination. In comparison to other microbial isolates, culture filtrates from three mushrooms, *i.e.*, *Lentinus edodes*, *Ganoderma lucidum and Clitocybe nuda* may completely prevent the germination of *Alternaria brassicicola* spores, thus, the bioactive ingredients found in mushrooms have the potential to be developed into biocontrol agents for a range of plant illnesses. Menaga *et al*. (2012) [75] revealed that the bioactive substances taken out of *Pleurotus florida* mushrooms can be used as substitute medication like antibiotics.

Mushroom as immunity booster

Mushrooms are an important natural source of immune-boosting ingredients. Hence, these can be used to treat specific immune-deficiency diseases such as tumors, cancer, tuberculosis and HIV as immune-modulating and immune-stimulating medicines. *Pleurotus* mushrooms contain bioactive compounds that can fortify the immune system. These bioactive compounds include functional proteins, polysaccharopeptides and polysaccharide-proteins (Including ubiquitin-like ubiquinone-9, peptide, nebrodeolysin and glycoprotein), glucans and proteoglycans (Oloke *et al.*, 2015) [80]. It has been shown that dietary white button mushrooms stimulate the migration of natural killer cells in mice. These cells play a vital role in the immune system and oversee the body's defense against viruses and tumors. More IFN-g and TNF-a production can counteract the elevated natural killer activity. Consuming *Agaricus bisporus* or white button mushrooms caused a shift toward a T-helper 1 response and a propensity for increased production of lymphocytes and IL-2 (Wu *et al.*, 2007) [113]. Jin *et al*. (2014) [49] discovered that *Agrocybe aegerita* contains a resistant lectin, which is not broken down by the digestive enzymes present in the human intestinal tract, which is connected to hepatotoxicity and a deadly protein.

Mushroom-based nutraceuticals in the market

Many mushrooms-based nutraceuticals are commercially available throughout the world. These products can be marketed in various forms like capsules, powders, mycelium extracts along with substrate and tablets, which are made of dried fruiting bodies (Wasser, 2005) [110]. Various nutraceuticals prepared from medicinal mushrooms (*Hericium erinaceus*) include Lions Mane capsules, which provide support to brain and nervous system (Hobbs, 1995) [42]. The extract and powder of Reishi mushroom (*Ganoderma lucidum*) show anti-viral effects like anti-HIV and anti-hepatitis B (Kino *et al.*, 1989; Kim *et al*., 1993; Liu and Chang, 1995) [58, 57, 70]. Cordyceps mushroom (*Cordyceps sinensis*) capsules help in memory improvement and restful sleep and act as an antiaging, anticancer and antiasthma agent (Sharma, 2008) [94]. Extract and powder prepared from Shiitake mushroom (*Lentinula edodes*) have antitumor properties, provide vigour to the human body, inhibit HIV and act as an antiaging agent (Gareth, 1990; Chihara *et al*., 1969). Oyster mushroom (*Pleurotus sajor-caju*) powder (20%) with other herbs supports immune health, strengthens bones, boosts energy levels and builds new cells and muscles (Tam *et al*., 1986) [101]. Maitake mushroom (*Grifola frondose*) extract acts as a tonic, helps in killing HIV, provides immune support (Nanba, 1993) [78] and many more. Besides these nutraceutical products, various mushrooms-based cosmetic and food products are also available in market.

Conclusion

Owing to enormous nutritional content, mushrooms have been regarded as a vital component of human diet since ancient time. Furthermore, because they are therapeutic in nature, mushrooms support the use of nutraceuticals. Many complex polysaccharides rich in proteins that confer various types of therapeutic characteristics, are found in mushrooms, as multiple scientific confirmations in the past have demonstrated. Few necessary mushrooms are among the edible mushrooms found in nature, which are often low in fat. Incorporating mushrooms in diet can aid in fighting against various nutritional deficiencies as they are high in macro- and micro-minerals. Regular ingestion of mushrooms can lead to the development of disease resistance.

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