International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
www.agronomyjournals.com
2024; 7(11): 129-139
Received: 21-09-2024
Accepted: 24-10-2024

Saurabh
University Institute of Agricultural Sciences, Chandigarh University, Gharuan, Punjab, India

Yumkhaibam Ambika Devi
University Institute of Agricultural Sciences, Chandigarh University, Gharuan, Punjab, India

Sahil Raj
University Institute of Agricultural Sciences, Chandigarh University, Gharuan, Punjab, India

Roochie Gautam
University Institute of Agricultural Sciences, Chandigarh University, Gharuan, Punjab, India

Garima Gupta
University Institute of Agricultural Sciences, Chandigarh University, Gharuan, Punjab, India

Corresponding Author:
Garima Gupta
University Institute of Agricultural Sciences, Chandigarh University, Gharuan, Punjab, India

Mushrooms as sustainable and healthy human food: Nutritional and medicinal attributes

Saurabh, Yumkhaibam Ambika Devi, Sahil Raj, Roochie Gautam and Garima Gupta

DOI: https://doi.org/10.33545/2618060X.2024.v7.i11b.1955

Abstract
Mushrooms, a versatile and nutritious food source, offer significant potential for sustainable human nutrition and health. This review delves into the medicinal and nutritional attributes of three prominent edible mushroom species: button, oyster, and shiitake. These fungi are abundant in vital elements, such as vitamins, minerals, and dietary fiber, all of which are beneficial to human health. Moreover, they contain bioactive compounds such as polysaccharides, β-glucans, and ergosterol, which have been linked to various health benefits. The paper explores the nutritional composition, and therapeutic properties of these mushrooms, highlighting their potential applications in functional foods, nutraceuticals, and pharmaceuticals. By understanding the benefits and sustainability of these fungi, we can promote their integration into diverse dietary practices, contributing to a healthier and more environmentally friendly food system.

Keywords: Nutritional, medicinal properties, edible, Constituents, human health, agriculture

Introduction
Since ancient times, mushrooms have been considered a staple of cuisines all over the world, prized for their extraordinary flavour, and considered a culinary wonder by humanity. As members of the kingdom of fungi, they are distinguished by their fleshy texture, cap, and gills beneath the cap (Sharma, 2018) [60]. There are currently around 14,000 known species of mushrooms, of which about 10% are categorized as macro-fungi. Only 10% of the estimated total number of mushrooms has been found to date (Abugri *et al.*, 2016) [1]. Because of their varied physiological functions and amazing flavour, edible mushrooms—which are macro-fungi that are visible to the unaided eye—have previously been used extensively in food and medicine (Qing *et al.*, 2021) [52].

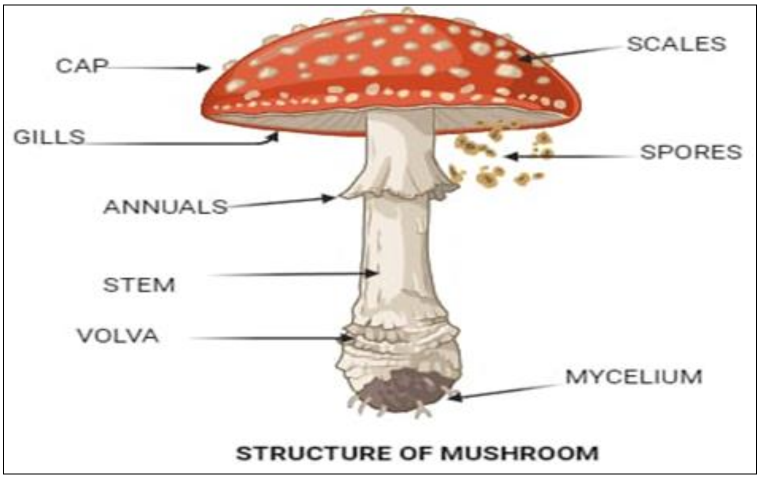

Fig 1: Different parts present in Mushroom

Some mushrooms are poisonous, whereas others are edible and found in the wild. In addition to being low in salt and high in vitamin B, copper, and selenium, they are composed of over 90% water and less than 1% fat (Sharma., 2018) [60]. According to Mhanda *et al*. (2015) [45], mushrooms are low in calories and cholesterol and have a high protein content (up to 44.93%), vitamins, fibers, minerals, and trace elements. Their high levels of polysaccharides, dietary fiber, proteo-glucan, and vitamins, such as riboflavin and thiamine, make them a valuable food source (Balan *et al*., 2018; Cardwell *et al*., 2018; Ślusarczyk *et al*., 2021) [9, 12, 65]. In addition, mushrooms are a natural and plentiful source of vitamin D, which is often acquired from livestock or poultry via direct addition or irradiation (Verma, 2023) [71]. This makes mushrooms unique among food sources. The main cause of this is the substantial amount of ergosterol, a plant sterol. When sunshine or artificial light sources are present, this sterol, which is a precursor for the production of vitamin D, transforms into the vitamin (Sharma, 2018) [60]. A delicacy with great nutritional and functional value, mushrooms are also recognised as nutraceutical foods. Oriental medicine has long utilized mushrooms to treat and prevent a wide range of illnesses. Their therapeutic qualities, economic relevance, and organoleptic value make them highly desirable (Ergönül *et al*., 2013) [31]. The scientific literature has extensively established the usage of edible mushrooms as a source of bioactive chemicals that support human health. A wide variety of bioactive chemicals found in mushrooms contribute to their health-promoting qualities, making them a desirable and adaptable addition to human diet (Valverde *et al*., 2015) [70]. Edible mushrooms, for example, have been found to contain phenolics/polyphenolics (Acar *et al*., 2021) [2], polysaccharides (Cateni *et al*., 2022) [13], lectins (El-Maradny *et al*., 2021) [25], terpenoids (Dasgupta and Acharya, 2019) [17], anti-oxidants (Taşkın *et al*., 2021) [69], and ergosterols (Saini *et al*., 2021; Nowak *et al*., 2022) [57, 49]. Although it might be difficult to tell the difference between medicinal and edible mushrooms, many popular edible species have therapeutic qualities, and some medicinal mushrooms are also edible (Guillamón *et al*., 2010) [30]. Preventive healthcare must include a well-balanced diet, especially when it comes to preventing oxidative stress. Because of its anticancer and immune-boosting qualities, mushroom extracts are already sold as dietary supplements (Finimundy *et al*., 2013) [27]. The purpose of this study was to investigate the nutritional value, chemical makeup, and possible commercial uses of the most extensively grown edible mushrooms in the world**.**

Status of Mushroom production in India

India's mushroom industry is growing, but the rest of the globe is responding to its mushroom output and consumption with lukewarmness. White button mushrooms are the main focus of the mushroom business in India; these are extremely complex and capital-intensive mushrooms. According to recent production data (official data from ICAR-DMR, Solan), button mushrooms account for the largest percentage of all mushrooms in India, accounting for 73%, with oyster mushrooms coming in second with a contribution of around 16%. In India, there are two primary categories of mushroom producers: those that cultivate white button mushrooms year-round in regulated environments and seasonal growers who plant button mushrooms in the north-western region of the country during the winter. An estimated 94676 metric tonnes of white button mushrooms are produced in India annually from both high-tech and seasonal growing units. Approximately 8500 metric tonnes of button mushrooms, or 9% of the total button mushroom production, were generated from the seasonal growing facilities in Punjab and Haryana. Farmers in the Punjab and Haryana regions have revolutionised seasonal farming with little inputs by skilfully using seasonal fluctuations. In this area, growing white button mushrooms is a source of money and a means of subsistence.

Types of mushrooms, their constituent parts and their biological importance

The *Laetiporus sulphureus* species of mushrooms contains polyunsaturated fatty acids, which are known to possess antibacterial and antifungal effects (Sinanoglou *et al*., 2015) [64]. In *Ganoderma lucidum*, ganoderic acid and beta-glucan have cytotoxic and antioxidant qualities (Kolniak *et al*., 2022) [39]. The *Agaricus bisporous* species of mushroom contains lectins, ribotoxins, catechin, polysaccharides, galactomannan, beta-glucan, and fatty acids. These compounds also have antibacterial, antiviral, antifungal, antioxidant, and anti-diabetic characteristics, and they also increase insulin secretion activity. Other species that contain lovastatin as an active component and can lower cholesterol are *Pleurotusostreatus*, *Pleurotus* spp., *and Pleurotus sajor-caju*. *Lentinan and eritadenine*, two species of *Lentinusedodes* that lower cholesterol, are among them (Soroko *et al*., 2022) [67]. *Grifolafrondosa* species have lectins and polysaccharides that work to reduce blood sugar and promote the synthesis of insulin (Liu *et al*., 2022). While the Auricular species has acidic polysaccharides with analgesic effects (Arunachalam *et al*., 2022) [4], *Cordyceps sinensis* has an active component called cordyceptin, which has hypoglycemic and anti-depressant properties (Karol *et al*., 2021; Arunachalam *et al*., 2022) [4]. Additionally, polysaccharide-K (Kresin), which has anti-cancer properties, is present in *Trametes versicolor*. The *Pleurotus giganteus* mushroom contains fatty acids, polysaccharides, and amino acids that have antioxidant and neuroprotective properties.

Nutritional and Medicinal properties of Oyster mushroom, Button mushroom and shiitake mushroom

Medicinal properties of oyster mushroom

Hepatoprotective, anti-cancer, and hemagglutination suppression are among the nutraceutical properties of these bioactive macromolecules, which comprise lectin flavonoids, polysaccharide, β-glucans, peptides, phenolics, and lovastatin (Rizkyana *et al*., 2022) [56]. Additionally, they offer low in calories, high-protein meals, chitin, fiber, vitamin D, and a decent profile of essential amino acids (Sassine *et al*., 2021) [76].

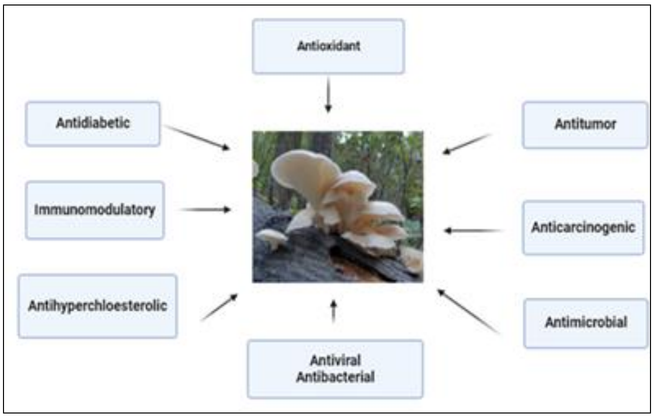

Fig 2: Different Medicinal properties of oyster mushroom

Antimicrobial

Pleurotus species are well known for their antiviral, antifungal, and antibacterial properties. *Pleurotus* species have shown considerable antibacterial activity due to the presence of several myco-constituents (Bhardwaj *et al*., 2020) [10]. Bacterial growth is considerably inhibited when the extract concentration increases from 25 to 100 µL/mL. The antifungal capacity of *P. eryngii* culture filtrate with *T. rubrum* was tested using the disc diffusion method. It was discovered that all tested concentrations of ethanolic extract significantly inhibited *T. rubrum* growth in comparison to the control and that the effect grew with concentration. The lowest values were 11.83 and 7.16 mm (12.5 and 6.25 mg/mL, respectively), whereas the highest concentration zone of inhibition was 18.66 mm (25 mg/mL). Furthermore, the results demonstrated that ethanolic extract functioned better than clotrimazole, an antifungal drug (Dawood *et al*., 2021) [18]. The ethanolic extract of *Pleurotus* species shown encouraging antibacterial activity against both Gram-positive and Gram-negative bacteria when tested using the agar well diffusion technique. According to Mishra *et al*. (2022) [46], the inhibition zones for *S. aureus, P. vulgaris, P. aeruginosa, and P. mirabilis* (200 mg/mL) were 29.6, 27.4, 24.4, and 16.4 mm, respectively. According to the aforementioned studies, extracts from *Pleurotus* species appear to be a more useful method of achieving antibacterial activity, especially in light of the rising worldwide concern over antibiotic usage and resistant bacteria.

Anti-tumor

In contrast with different mushrooms, *Pleurotus* species exhibited cytotoxic effects; the mycelium of this species includes water-soluble compounds known as proteoglycans that have immunomodulatory and anti-tumor actions. Eating mushrooms on a regular basis may help prevent prostate cancer since oyster mushrooms are known to have high quantities of L-ergothioneine, based to cohort research (Zhang *et al*., 2020) [78] on the association between incidence risk of prostate cancer and mushroom intake in Japan. (Haque *et al*., 2019) used human breast cancer cells (MCF-7) to examine the anti-tumor effectiveness of pure P. highking mushroom extract. To evaluate cell viability, they performed the MTT assay; to evaluate cell growth, they underwent the colony forming assay. The results show a strong anti-cancer activity via maintaining the pro-to-anti-apoptotic gene ratios. (Mishra *et al*., 2022) [46] used a number of assays, such as the nuclear morphological analysis of cancer cells, molecular docking, cell apoptosis, and the presto blue viability assay, to assess the effectiveness of the *Pleurotus* spp. (EEPO) ethanolic assay against the growth and proliferation of MCF-7. *Pleurotus* species were discovered to have significant anticancer activity because they prevented MCF-7 cells from growing and proliferating. They also caused cell loss of volume, nuclear disintegration, and membrane blebbing, all of which caused cancerous cells to undergo apoptosis.

Anti-hyperlipidaemia

Pleurotus spp. enzymatic residue polysaccharides (EnRPS) shown anti-hyperlipidemic effects in mice whose livers were injured by high fat, high cholesterol emulsion. Dong *et al*. (2019) [22] reported that 400 mg/kg bw of EnRPS significantly raised high-density lipoprotein (HDL) and decreased total cholesterol, total triglycerides, and low density lipoprotein (LDL). This implies that *P. ostreatus* may be utilized as an anti-hyperlipidemic and oxidative stress functional food. Treating hyperlipidemic rats with an oyster mushroom ultrasonic extract at high doses (500 mg/kg bw) caused the levels of triglycerides and total cholesterol to decrease, reaching 2.20 and 0.41 mmol/L, respectively, according to similar research.

Anti-diabetic

Diabetes mellitus (DM) is a broad spectrum of illnesses caused by decreased insulin production, insulin resistance, or a combination of the two, according to Elangovan *et al*. (2019) [24]. Despite advancements in diagnosis, management, and treatment, the incidence of diabetes mellitus continues to rise, increasing the risk of complications related to diabetes and, ultimately, morbidity and mortality (Harding *et al*., 2019) [34]. As a result, a growing number of people are showing interest in novel therapies with fewer side effects. In traditional medicine, mushrooms are used as side-effect-free remedies to control diabetes and blood sugar levels. In those with poor glucose tolerance, adding oyster mushroom powder to a meal significantly decreased postprandial glucose levels and non-esterified free fatty acid levels (Dicks *et al*., 2022**)** [21].

Anti-inflammatory

The active components of oyster mushrooms, including rutin, cinnamic acid, p-coumaric acid, and ascorbic acid, may have anti-inflammatory and antioxidant effects, claim Rahimah *et al*. (2019) [53]. Additionally, substances from *Pleurotus* species, including pleuron and lovastatin, have demonstrated potent anti-inflammatory qualities. Wistar rats administered 500–1,000 mg/kg of freeze-dried powdered oyster mushroom solutions showed a substantial reduction in LPS-induced cytokine production, NF-κB activation, and TNF-α release. These effects could be connected to the way carrageenan suppresses inflammation. A 5% dietary ethanol extract from golden oyster mushrooms dramatically decreased the levels of inflammatory cytokines and chemokines in rats with chronic colon inflammation (Yamashita *et al*., 2020) [77]. Its ability to reduce inflammation was investigated.

Immuno-stimulant

The immunostimulant potential of oyster mushroom nuggets in mice was investigated by Dewi *et al*. (2022) [19]. They found that 18 mg/kg bw oyster mushroom nuggets may increase lymphocyte cells (7.2 ± 1.22) × 103 cells/µL, suggesting that they are a promising source of immunostimulants. The aqueous extract of oyster mushrooms increases the secretion of nitric oxide (NO) and stimulates the production of inducible nitric oxide synthase (iNOS), which in turn increases the secretion of pro-inflammatory cytokines like TNF-α and IL-6, according to another study by (Maury *et al*., 2021), which was similar to the previous reports. Human faecal microbiota *in vitro* fermentation was used to study *P. eryngii's* immunomodulating properties (Vlassopoulou *et al*., 2022). Pro-inflammatory (TNF-α, IL-1) and anti-inflammatory (IL-10, IL-1R) cytokines were reduced.

Nutritional attributes of oyster mushroom

In recent decades, edible mushrooms have filled the protein gap by largely taking the place of grains like wheat, rice, and maize in diets. Several studies have shown that the nutritional content of *Pleurotus* spp. mushrooms is included in dried fruit bodies (Table 1). Assemie and Abaya (2022) [5] state that fresh *Pleurotus* species have an 85–95% moisture content. Phenolic acids, flavonoids, hydroxycinnamic acids, hydroxybenzoic acids, lignans, tannins, stilbenes, and oxidised polyphenols are among the approximately 100 different bioactive substances found in the fruiting body. Furthermore, dietary fibers, fat-free

carbohydrates, high protein, minerals (potassium, iron, copper, zinc, and manganese), and a substantial quantity of vitamins B1, B2, B12, C, D, E, and K are all abundant in *Pleurotus* species.
Actually, the second-most important kind of mushroom utilised in supplements for food worldwide is the dietary *Pleurotus* species. Mushrooms are regarded as a functional food that has health benefits in addition to its nutritional content. Protein, fiber, fat, ash, carbohydrates, minerals, and vitamins are all abundant in *Pleurotus ostreatus*, as Table 1 shows. This article addresses the single most common nutrient found in *Pleurotus ostreatus* mushrooms.

Table 1: Nutritional value of *Pleurotus ostreatus* on a dry weight basis (%).

Protein	Carbohydrates	Lipid	Fiber	References
17-42	37-48	0.5-5	24-31	(Chatterjee *et al*., 2021) [14]
32	50.9	3.1	6.2	(Raman *et al*., 2021) [54]
28.4	35.4	4.7	21.8	(Ferdousi *et al*., 2020) [26]
7.0	85.9	1.4	-	(Naeem *et al*., 2020) [48]
3.31	6.09	0.41	2.3	(Ho *et al*., 2020) [35]

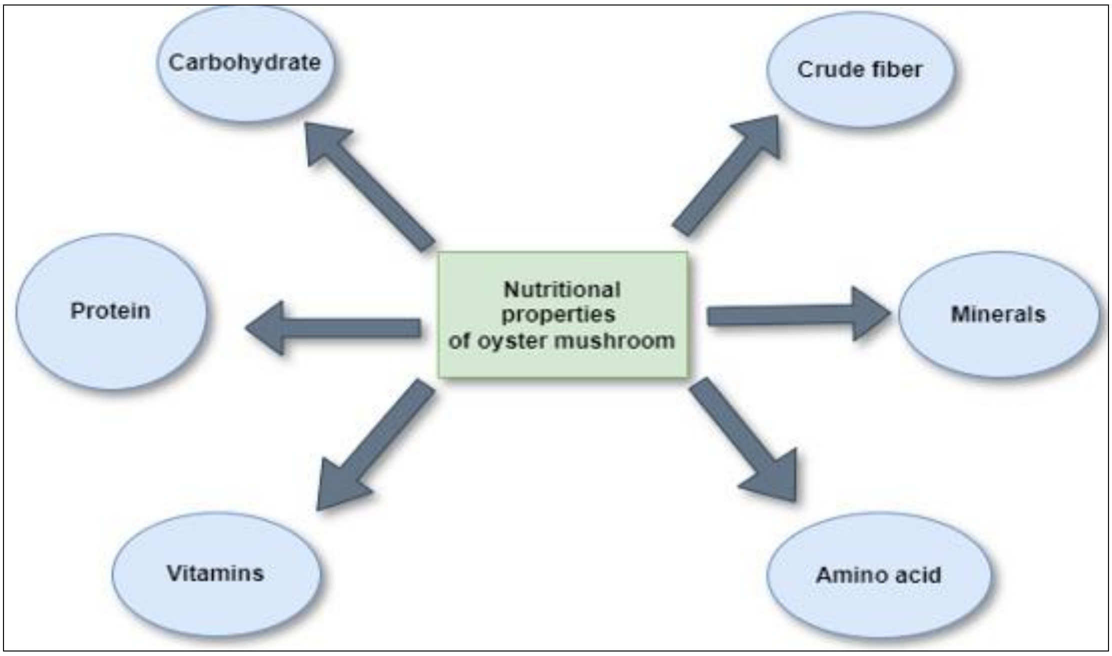

Fig 3: Various nutritional properties present in *oyster mushroom*

Carbohydrate and Crude Fiber
Starches, sugar alcohols, hexoses, pentoses, disaccharides, and amino sugars are among the many types of carbohydrates found in mushrooms. *Pleurotus* genus mushrooms are a fantastic source of carbohydrates and fiber from food. (Manikandan 2020) [44] The crude digestible fiber content of the mushroom is composed of partly digestible polysaccharides and chitin. The majority of *P. ostreatus's* carbohydrates are polysaccharides, which can be made up of many components such monosaccharides and their derivatives; they are also known as soluble sugars (Gupta *et al*., 2018) [32].

Protein Content and Amino Acid
The advantages of edible oyster mushrooms as a source of novel proteins are becoming more well recognised. These mushrooms often contain a lot of protein from crude sources. The protein composition of mushrooms varies by species and can vary from 12% to 35%, according to studies by Manikandan (2020) [44]. The digestibility of oyster mushroom protein is excellent, ranging from 72% to 83%. It has been shown that the strain type and the physical and chemical properties of the growth media affect the protein content of *Pleurotus* species. Several studies have found that the protein content of *Pleurotus* spp. mushrooms ranges from 17 g to 42 g per 100 g of dried fruit bodies.

Mineral
Mineral components are thought to be highly concentrated in mushroom fruiting bodies. The primary constituents are K, P, Na, Ca, and Mg; trace quantities of Cu, Zn, Fe, Mo, and Cd are also found. P. ostreatus is very common in Cu, Fe, K, Mg, P, Zn, and Na.

Vitamins
Mushroom fruit bodies appear to be high in vitamins, particularly B vitamins (thiamine, riboflavin, pyridoxine, pantothenic acid, nicotinic acid, nicotinamide, folic acid, and cobalamin), as well as vitamins C and D2. According to Gupta *et al*. (2018) [32], *P. ostreatus* mushrooms contain fewer amounts of B12, C, and B2, but are higher in folacin, vitamin B1, and vitamin B3. This has been demonstrated in several studies**.**

Nutritional and Medicinal properties of Shiitake Mushroom
The second most popular edible mushroom in the world is called *Lentinula edodes*, or *L. edodes*. It is farmed in Europe, Asia, Australia, and North America and is a member of the Omphalotaceae family. Shiitake accounts for 17% of the world's supply of edible fungus. broad (Sheng *et al*., 2021) [62]. The edible fungus *Lentinus edodes (*Berk.) Singer (*Lentinula edodes* (Berk.) Pegler, Marasmiaceae, Agarico mycetes) is grown and sold because of its medicinal and nutritional qualities (Diallo *et*

al., 2017 [20]; Gaitán-Hernández *et al*., 2017) [29]. Shiitake mushrooms are prized for their distinct, aromatic flavour; also, their high nutritional value is advantageous to health, and their bioactive compounds account for their popularity as therapeutic mushrooms (Rathore *et al*., 2017) [55]. A variety of growth conditions and substrates may be used to cultivate shiitake. The study we conducted compared the levels of ergosterol and amino acids in fruit bodies of *L. edodes* grown in the Occitanie area of France under organic and nonorganic growing conditions.

Medicinal attributes

Though not as strong as astragalus, shiitake (*Lentinus edodes*) has been demonstrated to have some of the same anti-inflammatory and anti-cancer properties. However, shiitake's therapeutic qualities and oral bioavailability have made it a widely eaten food item globally and a staple of traditional Chinese medicine for millennia (Wang *et al*., 2019 [73]; Wong *et al*., 2020) [75]. Shiitake's glucans, a class of D-glucose polysaccharides, are responsible for the majority of its anticancer and pro-apoptotic properties (Friedman *et al*., 2016; Sari *et al*., 2018) [28, 58]. Shiitake-produced glucans have been shown to have anticancer effects on triple-negative breast cancer cells and non-small-cell lung cancer cells, although their molecular weight is a decisive factor in these effects (Sari *et al*., 2018 [58] Curiously, the viability of cells was reduced by almost 90% after treatment with large molecule weight (>300 KDa) glucan, which is probably because of the stimulation-induced necrosis. On the other hand, small-molecule glucans (5 KDa) did not significantly inhibit the multiplication of cancer cells. Lentiman, a water-soluble polymer found in shiitake mushrooms, is among the best-characterized carbohydrates.

Its molecular composition is composed of an a-1, 3 glucopyranoside main chain and an a-1, 6 glucopyranoside branched chain (Ziaja-Sołtys *et al*., 2020) [80]. Both *in vitro* and *in vivo* anticancer action have been demonstrated to be transmitted by the lentinan β-glucan structure. Evidence exists to support the idea that lentinan's structural conformation plays a crucial role in its anticancer action; in fact, lentinan's triple-helix conformation exhibited a greater anticancer impact than its single flexible chain structure.

Astragalus and Shiitake May Be Used as Adjuvants in Chemotherapy

Apart from its medical benefits, chemotherapy also causes serious side effects such hair loss, exhaustion, infection, nausea, and vomiting, which severely reduces the quality of life for cancer patients. A very useful property of medicinal foods is their ability to increase the chemosensitivity of cancer cells, which enables the efficient lowering of chemotherapeutic dosages. This is in addition to their direct anticancer benefits**.** Additionally, APS may work in concert or as an addition to conventional chemotherapy drugs to minimize harmful side effects and lower the dosage of the former. According to a recent study, APS increases Adriamycin's apoptotic effects, when combined with Adriamycin on gastric cancer cells (Song *et al*., 2020) [66]. The findings of this study suggest that the AMPK pathway and APS might work in concert with Adriamycin to boost its anticancer activity, which is the mechanism behind the anticancer action. According to different research, lapatinib, a tyrosine kinase inhibitor that is used in many cancer treatments, may also work in concert or as an additive with other common chemotherapeutic drugs, lowering the dosage of chemotherapy and minimizing harmful side effects.

Immunomodulatory Functions of Astragalus and Shiitake in Tumor Immune Microenvironment

Severe immunosuppression, including weakened immune surveillance, is a hallmark of many cancer types. The main cause of this is the downregulation of major histocompatibility complex (MHC) class I molecules, a type of cell surface proteins that provides adaptive immune cells—which can destroy cancer cells—tumor-specific antigenic (Cornel *et al*., 2020) [15]. Other mechanisms that contribute to immune evasion include the inability of effector T cells to mediate cytotoxic responses within the tumor microenvironment, the expression of immune checkpoint inhibitors by tumor cells, the inability of dendritic cells, and trained antigen-presenting cells that infiltrate tumors to present tumor antigens (Wang *et al*., 2019) [73]. Increasing potent antitumor immunity has consequently emerged as a key cancer treatment strategy**.** Studies conducted *in vivo* and *in vitro* have demonstrated that shiitake and astragalus can boost immune responses in cancer treatment. When 5-FU was administered concurrently with APS, splenocyte growth and phagocytosis were both markedly boosted,by mouse peritoneal macrophages, which causes immunological activation and cancer development suppression (Liu *et al*., 2017) [42]. Tumor-promoting M2 macrophages and tumor-suppressing M1 macrophages are two subtypes of tumor-infiltrating macrophages. Remarkably, it has been demonstrated that APS therapy *in vivo* polarises macrophages to the M1 phenotype through the Notch signaling pathway, slowing the growth of malignancy (Wei *et al*., 2019) [74]. In a similar vein, research on APS (PG2)'s impact on antitumor immunogenicity.

Nutritional properties

With a dry matter concentration of more than 90%, the fresh fruit bodies of shiitake have comparatively less water on them. The dried mushrooms' approximate composition revealed that they contain between 58 and 60 percent carbohydrates. Approximately 20–23% protein and 9–10% fiber. The shiitake's protein extract has good digestion. Shiitake mushrooms are a fantastic source of the vitamin B complex. *Lentenula edodes* is found to have around 58–60% carbohydrates, 20–23% protein, 9–10% fiber, 3–4% fat, and 4-5 percent ash, according to research (Sheng *et al*., 2021; Hu *et al*., 2020; Morales *et al*., 2019) [62]. Except for the lower percentages of fat (1.3%) and fiber (1.3%), the other nutrients were found to be in comparable % found in University of Thessaly investigations. Moreover, it has been demonstrated that *L. edodes* possesses significant quantities of manganese, calcium, iron, phosphorus, potassium, and zinc. Moreover, it contains several bioactive compounds with noteworthy nutritional and pharmacological implications, such as polysaccharides, glycoproteins, and phenolic compounds (p-hydroxybenzoic, p-coumaric, and cinnamic acids) (Spim *et al*., 2021) [68]. Additionally, a randomized controlled study involving fifty-two adults in good health found that eating dried L. edodes for four weeks (5–10 g/day) may improve immunity by encouraging the proliferation of T cells and natural killer T (NK-T) cells while also lowering serum C-reactive protein (CRP) levels (Dai *et al*., 2015) [16]. Lastly, it has already been used to produce cereal bars that are both sweet and salty and have better nutritional and functional properties. Furthermore, according to the EFSA, it helps the body's immune system by boosting it and increasing specific immunocytes, which promotes the immune system's natural defences. The mushrooms' flavour, nutritional content, and potential for medicinal use all attracted customers to eat them. Customers ate the mushrooms because of their flavour, nutritional value, and potential for therapeutic application. Taste, texture, flavour, and colour are examples of palatability factors. Higher Basidiomycetes mushrooms are intrinsically superior nutritionally to a vegetarian diet in a number of ways. These include dietary fiber derived from a wall rich in chitin, a high protein content, essential amino acids that enable it to be used as a meat substitute, vitamin content (B1, B2, B12, C, D, and E), micro- and macro-elements, carbohydrates, low fat content, and almost zero cholesterol content (Liu *et al*., 2012). The scientific works examine the variety of amino acids, fatty acids, vitamins, minerals, and nucleic acids found in this mushroom in addition to analysing the proximate analysis. Owing to their low carbohydrate and cholesterol content and high protein content, mushrooms are a good choice for people with heart disease and diabetes. They may also be utilized to close the protein deficiency gap. As a result, research has been done on the ability of fungus loaded with vital components for human health to bioaccumulate nutrients (Silva *et al*., 2012) [63].

Nutritional and Medicinal Value of Bioactive Compounds in Button Mushroom

Several edible species with significant nutritional and medicinal value may be found in Agaricus, one of the biggest families of macrofungi (Zhang *et al*., 2017) [79]. The most highly cultivated mushroom in the Agaricaceae family, *Agaricus bisporus* (J. E. Lange) Imbach, is renowned for its edible nature. Due to its culinary and medicinal qualities is said to have been among the most important mushrooms. Throughout the past six to seven decades, there has been a steady rise in both the production and consumption of this mushroom. China is ranked first. One of the biggest genera of macrofungi, Agaricus contains a number of edible species with significant nutritional and therapeutic potential. One of the most commonly grown species is *Agaricus bisporus* (J. E. Lange) Imbach, a type of fungus belonging to the Agaricaceae family that is highly valued for its edible qualities. It is regarded as one of the most significant mushrooms because of its culinary and medicinal properties. The production and consumption of this specific mushroom has been steadily rising over the last six to seven decades. China is the country that produces the most *A. bisporus*. Russia, Japan, Vietnam, Korea, and Thailand are the countries that import the majority of its *A. bisporus*; a little proportion is also sent to Australia and a few other European and African countries. In addition to several European and African countries, *A. bisporus* is mostly sold to Russia, Japan, Vietnam, Korea, and Thailand; a limited amount is also shipped to Australia. Another name for *A. bisporus* is button mushroom, which is a useful food source that also contains a number of significant bioactive chemicals. In the last few years, *A. bisporus* has yielded several significant bioactive chemicals (Khan *et al*., 2015) [38]. Human health benefits from the nutritionally valuable bioactive substances found in *A. bisporus*.

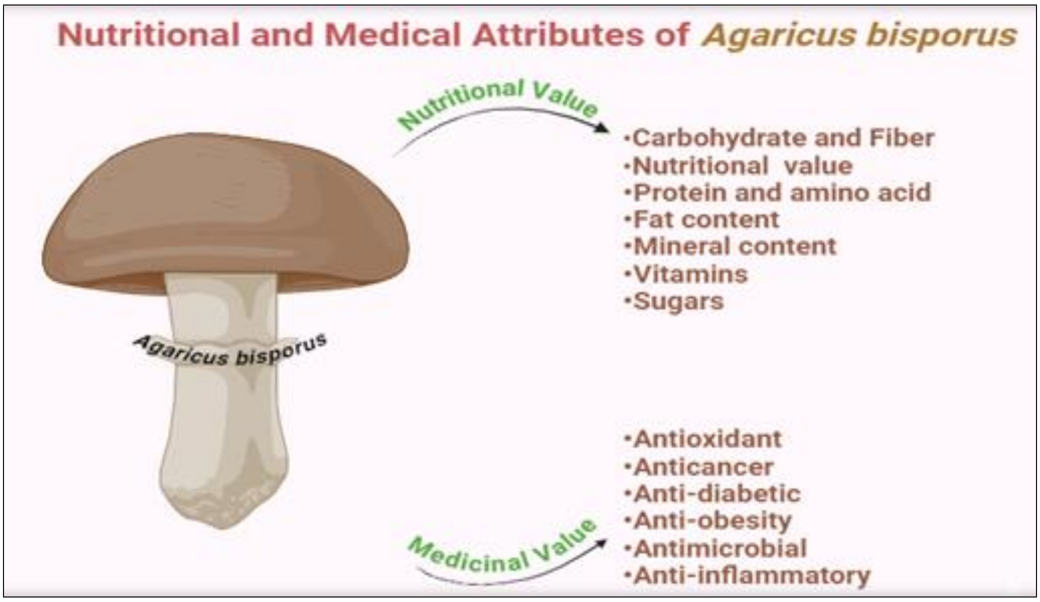

Fig 4: The nutritional and medicinal attributes of *Agaricus bisporus*.

Nutritional Values

Numerous investigations have been carried out to assess the nutritional worth of *A. bisporus*. The varied nutritional components of *A. bisporus* identified in various research are represented in Tables 2. Comparing *A. bisporus* to several other commonly consumed species, it is reasonably rich in proteins, lipids, and carbohydrates (Sebaaly *et al*., 2019) [23] state that mushrooms have varying nutritional values.

Raw Nutritional Value /100 g

Amino acids and proteins

Though they often rank lower than animal meats, mushrooms have rather high protein levels when compared to animal products.

Table 2: Nutritional status of *A. bisporus*

Energy	94 KJ (22kcal)
Water	92.43g
Fats	0.34g
Proteins	3.09g
Carbohydrates	3.26g
Dietary fibers	1g
Sugar	1.65g
Iron	0.50mg
Vitamin C	2.1mg
Niacin (VitB3)	3.607mg
Riboflavin (VitB2)	0.402mg
Pantothenic-acid (B5)	1.497mg

Source: USDA Nutrient database.

On the other hand, pre- and post-harvest circumstances are said to have an impact on the nutritional and chemical makeup of mushrooms. Furthermore, the quantities of protein and amino acid contents vary across the developmental stages of mushrooms (Cardoso *et al*., 2019) [11]. Variable protein concentrations are displayed by mushrooms growing on different substrates, according to reports from various researchers worldwide. Aspartic acid, serine, glycine, threonine, glutamine, valine, cysteine, alanine, leucine, isoleucine, lysine, histidine, proline, arginine, tyrosine, and orleucine are the main types of amino acids in *A. bisporus*. Furthermore, *A. bisporus's* crude protein levels varied from 19% to 38% on a dry weight basis. The goal of several previous investigations was to ascertain the total protein and amino acid composition of *A. bisporus*.

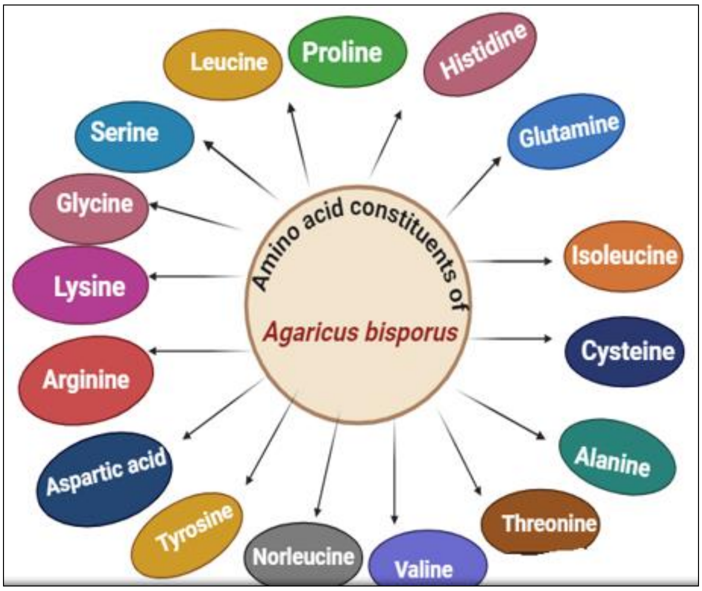

Fig 5: *A. bisporus* is rich in various forms of amino acid

Lipids

A. bisporus has a significant amount of important fatty acids, such as linoleic acid, but only trace levels of crude lipids. In contrast to strains of *A. bisporus* that are farmed, wild *Agaricus sp*. has comparatively higher levels of polyunsaturated fatty acids and lower concentrations of monounsaturated fatty acids (Baars *et al*., 2016) [8] states that the total fatty acid levels in *A. bisporus* ranged from 180 to 5818 mg kg 1DW, with linoleic acid accounting for nearly 90% of these values.

Fiber and Carbohydrates

Carbs are unquestionably a fundamental part of human diets, and mushrooms are an important source of both digestible and non-digestible carbs. The two major digestible carbohydrates, glucose and mannitol, are found in *A. bisporus* in small amounts (less than 1% of the dry weight). Additionally, another digestible carbohydrate that makes up 5–10% of *A. bisporus*'s dry weight is glycogen. Non-digestible carbohydrates, including as mannans, trehalose, and glucan, make up the majority of the carbohydrates in *A. bisporus*. The sugar that is most prevalent in *A. bisporus* is mannitol (Baars *et al*., 2016) [8]. The main type of soluble sugar in was mannitol.

Minerals

A. bisporus is regarded as a significant mineral source, primarily rich in manganese (Mn), copper (Cu), iron (Fe), cobalt (Co), selenium (Se), and potassium (K) (Owaid et.al 2017) [51] Phosphorus (P) and potassium (K) are the main mineral components of mushroom fruiting bodies, followed by calcium (Ca), zinc (Zn), iron (Fe), magnesium (Mg), and sodium (Na). These minerals are present in *A. bisporus* and contribute to the health advantages of the fungus.

Vitamins

Some studies have demonstrated the high vitamin content of mushrooms. Niacin and riboflavin were shown to be the most prevalent vitamins in *A. bisporus*, according to Ascorbic acid, vitamin B1, vitamin B3, tocopherol, and vitamin B3 were other crucial vitamins. *A. bisporus* has low in vitamin C content but high in riboflavin, folic acid, thiamin, and niacin. The mean values of vitamins B1 (thiamine) and B2 (riboflavin) from a fresh specimen of *A. bisporus* were determined. It is discovered that the values of vitamins B1 and B2 were 0.03 and 0.25 mg per 100 g, in that order. Furthermore, the quantities of vitamin B2 in *A. bisporus*, *Pleurotus* spp., and *L. edodes* were higher than those in different vegetables, except preserved mushrooms. This species is a good source of vitamin D (984 IU g 1).

Medicinal Attributes

Over time, there has been a global surge in interest in using mushrooms as a cure or treatment for numerous fatal illnesses. The best example of a fungus with excellent nutritional and therapeutic qualities is *A. bisporus*. *A. bisporus* has long been employed in traditional medicines in many different states and nations. Numerous investigations have verified that *A. bisporus* powder, extract, and even bioactive substances can be utilized to treat a range of fatal human illnesses. With each day that goes by, this pattern is becoming worse. It may be used to treat bacterial, fungal, viral, and immunological problems as well as diabetes mellitus, cancer, coronary heart disease, and immune system disorders. It also possesses potential anticancer, antioxidant, anti-obesity, and anti-inflammatory effects.

Properties of Antioxidants

In comparison to other significant edible, *A. bisporus* shows substantially better antioxidant capacity (Atila *et al*., 2017) [7]. Based on the fresh weight of fresh-cut *A. bisporus*. Additionally, the amounts of ergothioneine in brown and white *A. bisporus* varied between 0.21 and 45 mg g 1 DW. The main phenolic components found in the ethanolic extract of *A. bisporus* were analyzed and also verified the existence of naturally occurring antioxidants such myricetin, ferulic acid, gallic acid, protocatechuic acid, and catechin. Antioxidants have been verified by a few additional researchers to be present in *A. bisporus*.

Anticancer Properties

Cancer has remained one of the few serious illnesses on Earth throughout the past few decades. Recent studies have verified that several mushrooms' polysaccharides have strong anticancer properties, which inhibit cancer cell lines (Kothari *et al*., 2018). By reducing cellular immunity, *A. bisporus* polysaccharides have a major anti-cancer effect on malignant cells as *A. bisporus* is efficient against certain fatal diseases, increased use of the bacterium boosts immune functions, according to the Canadian Cancer Society. Numerous significant polysaccharides that have potent immune-stimulatory and antitumor properties both *in vitro* and *in vivo* are abundant in *A. bisporus*.

Anti-Diabetic Properties

A. bisporus has a high percentage of dietary fiber (19%) and other important carbohydrate elements, which may explain why it lowers blood sugar. Dietary fibers derived from *A. bisporus* have an impact akin to that of other valuable mushrooms. *A. bisporus* has higher levels of insulin and lower levels of glucose because of its lectin-like molecules. Because *A. bisporus* contains a large amount of fiber, it lowers blood glucose levels. High fiber contents in *A. bisporus* function as a barrier against the activity of digestive enzymes, which decreases the blood glucose level.

Activity to Combat Obesity

A prominent risk factor for hyperlipidemia is elevated triglyceride or cholesterol levels. In humans, it causes atherosclerosis and the most severe heart disorders. In addition to being incredibly nutrient-dense, mushrooms also show off a wealth of bioactive compounds (flavonoids, alkaloids, polysaccharides, polyphenols, fibers, sterols, and terpenes) that have the potential to act as antioxidants and positively impact a variety of cardiac biomarkers in the treatment of obesity and obesity-related cardiovascular diseases. Plant sterols, or phytosterols, have been shown by to decrease the absorption of cholesterol. LDL cholesterol and plasma cholesterol are decreased by phytosterols that are isolated from *A. bisporus*. *A. bisporus* also shows a significant quantity of lovastatin, which decreases cholesterol levels in the body to lessen the risk of cardiovascular problems.

Anti microbial and Anti-biotic attributes

Mushrooms are a natural source of antibiotics because they contain both low- and high-molecular-weight (LMW) molecules.

Table 3. *Agaricus bisporus* mycochemical analysis and activity.

Mycochemicals	Activities
Alkaloids	Antimicrobial, Anti-inflammatory, Antioxidant
Carbohydrate	Antimicrobial
Phenols and Polyphenols	Antimicrobial, Anti-inflammatory, Antioxidant
Protein and Amino acids	Antimicrobial, Anti-inflammatory
Saponins	Anticancer, Antioxidant
Tannins	Antimicrobial, Antioxidant

Source: **(**Muhammad *et al*., 2021).

Peptides and proteins make up HMW compounds whereas different kinds of steroids, sesqui-terpenes and other terpenes, anthraquinone, quinolines, and derivatives of benzoic acid are among the secondary metabolites that primarily comprise LMW compounds. A small number of primary metabolites, such as oxalic acid and those that have antibacterial properties, are also carried by the LMW (de Souza *et al*., 2017).

Another bioactive component that is widely present in many different plants, including *A. bisporus*, is gallic acid. It possesses strong natural anti-oxidant, anti-inflammatory, anti-tumor, anti-bacterial, and anti-fungal properties. *A. bisporus* methanolic extract is more active against *S. epidermidis, B. cereus, Bacillus subtilis, and Staphylococcus aureus*. Furthermore, it exhibits less potent effects against *Micrococcus luteus* and *M. flavus* showed the anti-microbial activity of different Agaricus species against diverse bacterial species (spp). According to Karnwal *et al*. (2020) [6], Affeic acid and rutin have been found to possess anti-microbial activity. Another bioactive component that is widely present in many different plants, including *A. bisporus*, is gallic acid. It possesses strong natural anti-oxidant, anti-inflammatory, anti-tumor, anti-bacterial, and anti-fungal properties. *A. bisporus* methanolic extract is more active against *S. epidermidis, B. cereus, Bacillus subtilis, and Staphylococcus aureus*. Furthermore, it exhibits less potent effects against *Micrococcus luteus and M. flavus*. According to certain Agaricus species have antimicrobial action against a range of bacterial species (spp).

Conclusions and Prospects for the Future

Mushrooms are a versatile and nutritious food source with significant potential for sustainable human nutrition and health. This review explores the medicinal and nutritional attributes of three prominent edible mushroom species: oyster, shiitake, and button mushrooms. These fungi are rich in essential nutrients, including proteins, carbohydrates, dietary fiber, vitamins, and minerals. They also contain bioactive compounds such as polysaccharides, β-glucans, ergosterol, and phenolic compounds, which have been linked to various health benefits. Oyster mushrooms exhibit antimicrobial, anti-tumor, anti-hyperlipidemic, anti-diabetic, anti-inflammatory, and immunostimulant properties. Shiitake mushrooms possess anticancer, immunomodulatory, and antioxidant activities, and may be used as adjuvants in chemotherapy. Button mushrooms have been shown to have antioxidant, anticancer, anti-diabetic, anti-obesity, and antimicrobial attributes. The nutritional composition and therapeutic properties of these mushrooms highlight their potential applications in functional foods, nutraceuticals, and pharmaceuticals. By understanding the benefits and sustainability of these fungi, we can promote their integration into diverse dietary practices, contributing to a healthier and more environmentally friendly food system. Further research is needed to elucidate the precise mechanisms underlying the treatment of specific diseases and to identify novel medicinal compounds in these mushrooms.

References

1. Abugri D, McElhenney WH, Willian KR. Fatty acid profiling in selected cultivated edible and wild medicinal mushrooms in Southern United States. J. Exp. Food Chem. 2016;2(01):1-7.
2. Acar İ, Blando F, Gul B, Greco A, Mukemre M, Uzun Y, Dalar A. The phenolic profile and biological activities of the wild-edible mushrooms *Helvella leucopus* and *Morchella pulchella*. Journal of Food Measurement and Characterization. 2021 Feb;15:555-566.
3. Ahlawat OP, Manikandan K, Singh M. Proximate composition of different mushroom varieties and effect of UV light exposure on vitamin D content in *Agaricus bisporus* and *Volvariella volvacea*. Mushroom Research. 2016, 25(1).
4. Arunachalam K, Sreeja PS, Yang X. The antioxidant properties of mushroom polysaccharides can potentially mitigate oxidative stress, beta-cell dysfunction and insulin resistance. Frontiers in Pharmacology. 2022 May 5;13:874474.
5. Assemie A, Abaya G. The effect of edible mushroom on health and their biochemistry. International journal of microbiology. 2022;2022(1):8744788.
6. Karnwal A, Kaur M. Assessment of *Agaricus bisporus* S-II extract as a bio-controlling agent against human pathogenic bacterial species. Archives of Razi Institute. 2020;75(1):123.
7. Atila F, Owaid MN, Shariati MA. The nutritional and medical benefits of *Agaricus bisporus*: A review; c2017

8. Baars JJ, Sonnenberg AS, Mumm R, Stijger I, Wehrens HR. Metabolites contributing to taste in *Agaricus bisporus*. Plant Research International; c2016.
9. Balan V, Munafo Jr JP, Pattathil S, Merritt BB, Venketachalam S, Ng WO. Protocols to Evaluate the Nutritional and Potential Health Benefits of Edible Mushrooms. Current Biotechnology. 2018 Feb 1;7(1):34-58.
10. Bhardwaj K, Sharma A, Tejwan N, Bhardwaj S, Bhardwaj P, Nepovimova E, *et a*l. *Pleurotus* macrofungi-assisted nanoparticle synthesis and its potential applications: a review. Journal of Fungi. 2020 Dec 9;6(4):351.
11. Cardoso RV, Fernandes Â, Barreira JC, Verde SC, Antonio AL, Gonzaléz-Paramás AM, et al, Ferreira IC. Effectiveness of gamma and electron beam irradiation as preserving technologies of fresh *Agaricus bisporus* Portobello: A comparative study. Food chemistry. 2019 Apr 25;278:760-6.
12. Cardwell G, Bornman JF, James AP, Black LJ. A review of mushrooms as a potential source of dietary vitamin D. Nutrients. 2018 Oct 13;10(10):1498.
13. Cateni F, Gargano ML, Procida G, Venturella G, Cirlincione F, Ferraro V. Mycochemicals in wild and cultivated mushrooms: nutrition and health. Phytochemistry Reviews. 2022 Apr;21(2):339-83.
14. Chatterjee D, Halder D, DAS S. Varieties of Mushrooms and their Nutraceutical Importance: A Systematic Review. Journal of Clinical & Diagnostic Research. 2021, 15(3).
15. Cornel AM, Mimpen IL, Nierkens S. MHC class I downregulation in cancer: underlying mechanisms and potential targets for cancer immunotherapy. Cancers. 2020 Jul 2;12(7):1760.
16. Dai X, Stanilka JM, Rowe CA, Esteves EA, Nieves Jr C, Spaiser SJ, *et al*. Consuming *Lentinula edodes* (Shiitake) mushrooms daily improves human immunity: A randomized dietary intervention in healthy young adults. Journal of the American College of Nutrition. 2015 Nov 2;34(6):478-87.
17. Dasgupta A, Acharya K. Mushrooms: an emerging resource for therapeutic terpenoids. 3 Biotech. 2019 Oct;9(10):369.
18. Dawood SM, Abdulrazzaq AK, Shnawa KT, Hanawi MJ. *In vitro* Antifungal Activity of of *Pleurotus*eryngii against Trichophytonrubrum. Indian Journal of Forensic Medicine & Toxicology. 2021 Aug 16;15(4):2363-70.
19. Dewi AD, Mukti YP. Immunostimulant Potential of Oyster Mushroom Nugget (*Pleurotus ostreatus*). Jurnal Pangan dan Agroindustri. 2022 May 9;10(2).
20. Diallo I, Alain M, Poucheret P, Sylvie M, Manon V, Traoré L, *et al*. *Lentinula edodes* (Shiitake), an edible nutritional and medicinal mushroom: Health benefits and risks. IniCEPS Conference 2017, 5ème édition. Non-pharmacological interventions: from methodology to evidence of efficacy 2017 May 18 (pp. Poster-E9).
21. Dicks L, Jakobs L, Sari M, Hambitzer R, Ludwig N, Simon MC, *et al*. Fortifying a meal with oyster mushroom powder beneficially affects postprandial glucagon-like peptide-1, non-esterified free fatty acids and hunger sensation in adults with impaired glucose tolerance: a double-blind randomized controlled crossover trial. European Journal of Nutrition. 2022 Mar 1:1-5.
22. Dong Y, Zhang J, Gao Z, Zhao H, Sun G, Wang X, *et al*. Characterization and anti-hyperlipidemia effects of enzymatic residue polysaccharides from *Pleurotus ostreatus*. International journal of biological macromolecules. 2019 May 15;129:316-25.
23. El Sebaaly Z, Assadi F, Sassine YN, Shaban N. Substrate types effect on nutritional composition of button mushroom (*Agaricus bisporus*). Poljoprivreda i Sumarstvo. 2019;65(1):73-80.
24. Elangovan A, Subramanian A, Durairaj S, Ramachandran J, Lakshmanan DK, Ravichandran G, *et al*. Antidiabetic and hypolipidemic efficacy of skin and seed extracts of Momordica cymbalaria on alloxan induced diabetic model in rats. Journal of ethnopharmacology. 2019 Sep 15;241:111989.
25. El-Maradny YA, El-Fakharany EM, Abu-Serie MM, Hashish MH, Selim HS. Lectins purified from medicinal and edible mushrooms: Insights into their antiviral activity against pathogenic viruses. International journal of biological macromolecules. 2021 May 15;179:239-58.
26. Ferdousi J, Riyadh ZA, Hossain MI, Saha SR, Zakaria M. Mushroom production benefits, status, challenges and opportunities in Bangladesh: A review. Annual Research & Review in Biology. 2020 Mar 12;34(6):1-3.
27. Finimundy TC, Gambato G, Fontana R, Camassola M, Salvador M, Moura S, *et al*. Aqueous extracts of *Lentinula edodes* and *Pleurotus* sajor-caju exhibit high antioxidant capability and promising *in vitro* antitumor activity. Nutrition research. 2013 Jan 1;33(1):76-84.
28. Friedman M. Mushroom polysaccharides: chemistry and antiobesity, antidiabetes, anticancer, and antibiotic properties in cells, rodents, and humans. Foods. 2016 Nov 29;5(4):80.
29. Gaitán-Hernández R, Zavaleta MA, Aquino-Bolaños EN. Productivity, physicochemical changes, and antioxidant activity of shiitake culinary-medicinal mushroom *Lentinus edodes* (Agaricomycetes) cultivated on lignocellulosic residues. International Journal of Medicinal Mushrooms. 2017, 19(11).
30. Guillamón E, García-Lafuente A, Lozano M, Rostagno MA, Villares A, Martínez JA. Edible mushrooms: role in the prevention of cardiovascular diseases. Fitoterapia. 2010 Oct 1;81(7):715-723.
31. Günç Ergönül P, Akata I, Kalyoncu F, Ergönül B. Fatty acid compositions of six wild edible mushroom species. The Scientific World Journal. 2013;2013(1):163964.
32. Gupta S, Summuna B, Gupta M, Annepu SK. Edible mushrooms: cultivation, bioactive molecules, and health benefits. Bioactive molecules in food. 2018;1:1-33.
33. Haque MA, Islam MA. *Pleurotus* highking mushroom induces apoptosis by altering the balance of proapoptotic and antiapoptotic genes in breast cancer cells and inhibits tumor sphere formation. Medicina. 2019 Oct 28;55(11):716.
34. Harding JL, Pavkov ME, Magliano DJ, Shaw JE, Gregg EW. Global trends in diabetes complications: a review of current evidence. Diabetologia. 2019 Jan;62:3-16.
35. Ho LH, Zulkifli NA, Tan TC. Edible mushroom: nutritional properties, potential nutraceutical values, and its utilisation in food product development. An introduction to mushroom. 2020 May 1;10.
36. Hu D, Chen W, Li X, Yue T, Zhang Z, Feng Z, *et al*. Ultraviolet irradiation increased the concentration of vitamin D2 and decreased the concentration of ergosterol in shiitake mushroom (*Lentinus edodes*) and oyster mushroom (*Pleurotus ostreatus*) powder in ethanol suspension. ACS omega. 2020 Mar 23;5(13):7361-8.
37. Jędrejko KJ, Lazur J, Muszyńska B. Cordyceps militaris: An overview of its chemical constituents in relation to biological activity. Foods. 2021 Oct 30;10(11):2634.

38. Khan AA, Gani A, Shah A, Masoodi FA, Hussain PR, Wani IA, *et al*. Effect of γ-irradiation on structural, functional and antioxidant properties of β-glucan extracted from button mushroom (*Agaricus bisporus*). Innovative Food Science & Emerging Technologies. 2015 Oct 1;31:123-130.
39. Kolniak-Ostek J, Oszmiański J, Szyjka A, Moreira H, Barg E. Anticancer and antioxidant activities in Ganoderma lucidum wild mushrooms in Poland, as well as their phenolic and triterpenoid compounds. International journal of molecular sciences. 2022 Aug 19;23(16):9359.
40. Kothari D, Patel S, Kim SK. Anticancer and other therapeutic relevance of mushroom polysaccharides: A holistic appraisal. Biomedicine & Pharmacotherapy. 2018 Sep 1;105:377-394.
41. Li W, Hu X, Wang S, Jiao Z, Sun T, Liu T, *et al*. Characterization and anti-tumor bioactivity of astragalus polysaccharides by immunomodulation. International Journal of Biological Macromolecules. 2020 Feb 15;145:985-997.
42. Liu AJ, Yu J, Ji HY, Zhang HC, Zhang Y, Liu HP. Extraction of a novel cold-water-soluble polysaccharide from Astragalus membranaceus and its antitumor and immunological activities. Molecules. 2017 Dec 28;23(1):62.
43. Liu YT, Sun J, Luo ZY, Rao SQ, Su YJ, Xu RR, *et al*. Chemical composition of five wild edible mushrooms collected from Southwest China and their antihyperglycemic and antioxidant activity. Food and Chemical Toxicology. 2012 May 1;50(5):1238-44.
44. Manikandan AK. Topic nutritional and values of mushrooms assistant professor in botan; c2020.
45. Mhanda FN, Kadhila-Muandingi NP, Ueitele IS. Minerals and trace elements in domesticated Namibian Ganoderma species. African Journal of Biotechnology. 2015;14(48):3216-8.
46. Mishra V, Tomar S, Yadav P, Vishwakarma S, Singh MP. Elemental analysis, phytochemical screening and evaluation of antioxidant, antibacterial and anticancer activity of *Pleurotus ostreatus* through *in vitro* and in silico approaches. Metabolites. 2022 Aug 31;12(9):821.
47. Morales D, Tejedor-Calvo E, Jurado-Chivato N, Polo G, Tabernero M, Ruiz-Rodríguez A, *et al*. *In vitro* and *in vivo* testing of the hypocholesterolemic activity of ergosterol-and β-glucan-enriched extracts obtained from shiitake mushrooms (*Lentinula edodes*). Food & function. 2019;10(11):7325-32.
48. Naeem MY, Ozgen S, Rani S. Emerging role of edible mushrooms in food industry and its nutritional and medicinal consequences. Eurasian Journal of Food Science and Technology. 2020;4(1):6-23.
49. Nowak R, Nowacka-Jechalke N, Pietrzak W, Gawlik-Dziki U. A new look at edible and medicinal mushrooms as a source of ergosterol and ergosterol peroxide-UHPLC-MS/MS analysis. Food chemistry. 2022 Feb 1;369:130927.
50. Usman M, Murtaza G, Ditta A. Nutritional, medicinal, and cosmetic value of bioactive compounds in button mushroom (*Agaricus bisporus*): a review. Applied Sciences. 2021 Jun 26;11(13):5943.
51. Owaid MN, Barish A, Ali Shariati M. Cultivation of *Agaricus bisporus* (button mushroom) and its usages in the biosynthesis of nanoparticles. Open Agriculture. 2017 Oct 26;2(1):537-543.
52. Qing Z, Cheng J, Wang X, Tang D, Liu X, Zhu M. The effects of four edible mushrooms (*Volvariella volvacea*, Hypsizygus marmoreus, *Pleurotus ostreatus* and *Agaricus bisporus*) on physicochemical properties of beef paste. Lwt. 2021 Jan 1;135:110063.
53. Rahimah SB, Djunaedi DD, Soeroto AY, Bisri T. The phytochemical screening, total phenolic contents and antioxidant activities *in vitro* of white oyster mushroom (*Pleurotus ostreatus*) preparations. Open access Macedonian journal of medical sciences. 2019 Aug 8;7(15):2404.
54. Raman J, Jang KY, Oh YL, Oh M, Im JH, Lakshmanan H, Sabaratnam V. Cultivation and nutritional value of prominent *Pleurotus* spp.: an overview. Mycobiology. 2021 Jan 2;49(1):1-4.
55. Rathore H, Prasad S, Sharma S. Mushroom nutraceuticals for improved nutrition and better human health: A review. PharmaNutrition. 2017 Jun 1;5(2):35-46.
56. Rizkyana AD, Ho TC, Roy VC, Park JS, Kiddane AT, Kim GD, Chun BS. Sulfation and characterization of polysaccharides from Oyster mushroom (*Pleurotus ostreatus*) extracted using subcritical water. The Journal of Supercritical Fluids. 2022 Jan 1;179:105412.
57. Saini RK, Rauf A, Khalil AA, Ko EY, Keum YS, Anwar S, *et al*, Rengasamy KR. Edible mushrooms show significant differences in sterols and fatty acid compositions. South African Journal of Botany. 2021 Sep 1;141:344-356.
58. Sari M, Toepler K, Nickisch-Hartfiel A, Teusch N, Hambitzer R. Cross-flow ultrafiltration fractions of a cold aqueous extract of the shiitake culinary-medicinal mushroom, *Lentinus edodes* (Agaricomycetes), exhibit apoptosis in tumor cells. International Journal of Medicinal Mushrooms. 2018;20(11).
59. Fouda S, Salem MS, Saeed A, Shaker A, Abouelatta M. Thirteen-level modified packed u-cell multilevel inverter for renewable-energy applications. In2020 2nd International Conference on Smart Power & Internet Energy Systems (SPIES) 2020 Sep 15 (pp. 431-435). IEEE.
60. Sharma K. Mushroom: Cultivation and processing. Int. J. of Food Processing Technology. 2018;5(2):9-12.
61. Shbeeb DA, Farahat MF, Ismail HM. Macronutrients analysis of fresh and canned *Agaricus bisporus* and *Pleurotus ostreatus* mushroom species sold in Alexandria markets, Egypt. Egypt. Prog. Nutr. 2019 Dec 1;21:203-209.
62. Sheng K, Wang C, Chen B, Kang M, Wang M, Liu K, *et al*. Recent advances in polysaccharides from *Lentinus edodes* (Berk.): Isolation, structures and bioactivities. Food chemistry. 2021 Oct 1;358:129883.
63. Silva S, Martins S, Karmali A, Rosa E. Production, purification and characterisation of polysaccharides from *Pleurotus ostreatus* with antitumor activity. Journal of the Science of Food and Agriculture. 2012 Jul;92(9):1826-32.
64. Sinanoglou VJ, Zoumpoulakis P, Heropoulos G, Proestos C, Ćirić A, Petrovic J, *et al*. Lipid and fatty acid profile of the edible fungus Laetiporus sulphurous. Antifungal and antibacterial properties. Journal of Food Science and Technology. 2015 Jun;52:3264-72.
65. Ślusarczyk J, Adamska E, Czerwik-Marcinkowska J. Fungi and algae as sources of medicinal and other biologically active compounds: A review. Nutrients. 2021 Sep 12;13(9):3178.
66. Song J, Chen Y, He D, Tan W, Lv F, Liang B, *et al*. Astragalus polysaccharide promotes adriamycin-induced apoptosis in gastric cancer cells. Cancer management and research. 2020 Apr 1:2405-14.
67. Soroko M, Górniak W, Zielińska P, Górniak A, Śniegucka K, Nawrot K, Korczyński M. Effect of *Lentinula edodes* on

morphological and biochemical blood parameters of horses. Animals. 2022 Apr 25;12(9):1106.

68. Spim SR, Castanho NR, Pistila AM, Jozala AF, Oliveira Júnior JM, Grotto D. *Lentinula edodes* mushroom as an ingredient to enhance the nutritional and functional properties of cereal bars. Journal of Food Science and Technology. 2021 Apr;58:1349-57.
69. Taşkın H, Süfer Ö, Attar ŞH, Bozok F, Baktemur G, Büyükalaca S, *et al*. Total phenolics, antioxidant activities and fatty acid profiles of six Morchella species. Journal of Food Science and Technology. 2021 Feb;58:692-700.
70. Valverde ME, Hernández-Pérez T, Paredes-López O. Edible mushrooms: improving human health and promoting quality life. International journal of microbiology. 2015;2015(1):376387.
71. Verma S. Mushroom cultivation: A sustainable approach to future agriculture to ensure quality food and nutritional security of current population in India; c2023
72. Vlassopoulou M, Paschalidis N, Savvides AL, Saxami G, Mitsou EK, Kerezoudi EN, *et al*. Immunomodulating activity of *Pleurotus* eryngii mushrooms following their *in vitro* fermentation by human fecal microbiota. Journal of Fungi. 2022 Mar 22;8(4):329.
73. Wang T, He H, Liu X, Liu C, Liang Y, Mei Y. Mycelial polysaccharides of *Lentinus edodes* (shiitake mushroom) in submerged culture exert immunoenhancing effect on macrophage cells via MAPK pathway. International journal of biological macromolecules. 2019 Jun 1;130:745-754.
74. Wei W, Li ZP, Bian ZX, Han QB. Astragalus polysaccharide RAP induces macrophage phenotype polarization to M1 via the notch signaling pathway. Molecules. 2019 May 27;24(10):2016
75. Wong JH, Ng TB, Chan HH, Liu Q, Man GC, Zhang CZ, *et al*. Mushroom extracts and compounds with suppressive action on breast cancer: evidence from studies using cultured cancer cells, tumor-bearing animals, and clinical trials. Applied Microbiology and Biotechnology. 2020 Jun;104:4675-703.
76. Sassine YN, Naim L, El Sebaaly Z, Abou Fayssal S, Alsanad MA, Yordanova MH. Nano urea effects on *Pleurotus ostreatus* nutritional value depending on the dose and timing of application. Scientific reports. 2021 Mar 10;11(1):5588.
77. Yamashita S, Akada K, Matsumoto S, Kinoshita M. Effects of dietary ethanol extract from fruiting bodies of golden oyster mushroom (*Pleurotus* citrinopileatus) on chronic colon inflammation in mice treated with dextran sulfate sodium salt. Mushroom Science and Biotechnology. 2020;28(1):7-14.
78. Zhang S, Sugawara Y, Chen S, Beelman RB, Tsuduki T, Tomata Y, *et al*. Mushroom consumption and incident risk of prostate cancer in Japan: A pooled analysis of the Miyagi Cohort Study and the Ohsaki Cohort Study. International journal of cancer. 2020 May 15;146(10):2712-20.
79. Zhang MZ, Li GJ, Dai RC, Xi YL, Wei SL, Zhao RL. The edible wide mushrooms of Agaricus section Bivelares from Western China. Mycosphere. 2017 Jan 1;8(10):1640Ğ1652.
80. Ziaja-Sołtys M, Radzki W, Nowak J, Topolska J, Jabłońska-Ryś E, Sławińska A, *et al*, Bogucka-Kocka A. Processed fruiting bodies of *Lentinus edodes* as a source of biologically active polysaccharides. Applied Sciences. 2020 Jan 8;10(2):470.