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Unveiling the Nutritional, Therapeutic, and Environmental Impact of Oyster Mushrooms (*Pleurotus* species): A Review

Priyanka Nayak [a], Amit Mani Tiwari [b], Sushil Kumar Chauhan [a] and Sanjay Mishra [c*]

[a] Regional Food Research and Analysis Centre, Udyan Bhavan Campus, 2, Sapru Marg, Lucknow-226001, U.P., India.
[b] Department of Biotechnology, Era University, Lucknow-226003, U.P., India.
[c] Department of Biotechnology, SR Institute of Management & Technology, Bakshi ka Talab, NH-24, Lucknow-226201, U.P., India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Mushrooms have become gradually prominent in modern diets, with a surge in consumption across a diverse array of species. Among these, the genus *Pleurotus*, colloquially known as "Oyster mushrooms", stands out, boasting nearly 40 distinct species. *Pleurotus ostreatus* (*P. ostreatus*), in particular, relishes widespread popularity globally due to its mouth-watering taste, appealing flavor

**Corresponding author: E-mail: sanjaymishra66@gmail.com;*

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profile, and remarkable nutritional profile. Well-known for its abundance of indispensable nutrients and bioactive compounds, *P. ostreatus* has been the subject of extensive research highlighting its many-sided medicinal properties. Studies have projected its potential as an antidiabetic, antibacterial, anticholesterol, antiarthritic, antioxidant, anticancer, and antiviral agent, concomitant with encouraging eye health. This review underscores the remarkable nutritional richness of *P. ostreatus* and delves into its profound implications for medicinal applications, positioning these mushrooms as indispensable nutraceutical functional foods with vast therapeutic potential.

Keywords: Antiarthritic; antibacterial; anticancer; antidiabetic; antioxidant; oyster mushrooms; Pleurotus ostreatus.

1. INTRODUCTION

Mushrooms are fungi; their potential as nutritional powerhouses have been largely undervalued. Oyster mushrooms (*Pleurotus* species) as a largely consumed and nutritionally rich variety, initiating from Asia but now cultivated globally. Initially it was used as substitute food source especially during First World War. Later on, it has risen to develop the third most commercially produced mushroom wide-reaching because of its nutritional status.

Oyster mushrooms, frequently overlooked in spite of their nutritional affluence, represent a veritable treasure trove of essential nutrients. While their significance may have been underappreciated in some parts of the world, particularly in Western cultures, the eastern hemisphere has long documented the therapeutic potential of several mushroom species, including oyster mushrooms, in traditional medicine practices straddling millennia. Rich in riboflavin, pantothenic acid, niacin, selenium, copper, potassium, and vitamin D, these fungi propose a wide-ranging arrangement of vital nutrients essential for human health serve as admirable health supplements [1]. Factually, Oyster mushrooms have held a valued status in Asian continental regions, where they have been exploited for medicinal drives since ancient periods. Current research has been explicated for their potential therapeutic standards against hypercholesterolemia, hypertension, diabetes, cancer, infections, neurodegenerative diseases, infertility, positioning oyster mushrooms as hopeful candidates for further exploration in the area of integrative medicine and pharmacology [2-4].

In existing decade, the Oyster mushroom arises as a standout competitor in the global mushroom market, with several species cultivated on both small and large scales across the world [5,6]. *Pleurotus* species, specifically, flourish on various agricultural wastes, owing to their greater wood disintegrating capabilities compared to other mushroom varieties [7,8]. The nutritional conformation of *Pleurotus* species is influenced by numerous factors including genetic makeup, disparities in the physical and chemical characteristics of the growth medium [8,9], substrate type, pileus size, and harvesting period. Medicinally advantageous *Pleurotus* species are characteristically capable with high levels of protein, minerals (like sodium, potassium, iron, calcium and phosphorus), and vitamins (including folic acid, niacin, riboflavin and thiamine) [10,11], as well as proximate composition constituents, namely, protein, fat, ash, carbohydrates, and energy [12-14]. Moreover, sugars such as fructose, mannitol, sucrose, trehalose, and fatty acids principally palmitic, oleic, stearic, linoleic, and linolenic acids have been recognized in *Pleurotus* species [12,15]. Remarkably, Oyster mushrooms reveal high potassium to sodium ratio, interpreting them a finest dietary prime for individuals distressed with hypertension and cardio-metabolic disorders [16,17]. *Pleurotus* species symbolizes a rich source of nutraceutical compounds, with lectins evolving as prominent glycoproteins having many-sided bioactivities like antitumor, immune modulator, and antiproliferative features [7-9]. In addition, polysaccharides, namely, β-glucan, polysaccharopeptides, and polysaccharide proteins derived from *Pleurotus* display pharmaceutical potential, demonstrating hepatoprotective, anti-inflammatory, immune-enhancing, and anticancer features. Particularly, heteroglycans from *Pleurotus* species have been noticed to excite macrophages whereas exerting anti-proliferative and proapoptotic effects on carcinoma cells, underlining their therapeutic potential in oncology [15,18,19]. Researchers purified a homogeneous, branched β-1,6-glucan (APEP-A-b) from the fruiting bodies of *P. eryngii* and determined its effects on immunity and gut microbiota in mice. They found that APEP-A-b suggestively increases splenic lymphocyte proliferation, NK cell activity, and phagocytic capacity of peritoneal cavity phagocytes. Besides, the amount of CD_4^+ and CD_8^+ T cells in lamina propria were significantly increased upon treatment with APEP-A-b [20]. APEP-A-b also increases the amount of SCFAs produced in bacteria to promote production of acetic and butyric acid. Overall, our results suggest that β-1,6-glucan from *P. eryngii* improves immunity might by modulating the gut microbiota. Also, the phytochemical repertoire of *Pleurotus* includes varied compounds, together with alkaloids, saponins, steroids, flavonoids, anthraquinones and phlobatannins, each being contributory to its pharmacological arsenal. Phenolic compounds, observed as crucial secondary metabolites within *Pleurotus* species, display a range of physiological aids ranging from anti-inflammatory and antiallergenic features to cardioprotective, antiatherogenic, antimicrobial, antithrombotic, and antioxidant functions [5,21, 22]. Such multi-functional features position *Pleurotus* as a promising means for emerging therapeutic agents encounter several deteriorating disorders, symbolizing the latent synergy between natural products and modern pharmacotherapy [12,15].

Free radicals, stemming from several sources like ultraviolet light exposure, cellular metabolism, and environmental pollutants, epitomize a daunting challenge to human health. These highly reactive molecules can persuade inflammation and impose damage upon immune cells and other vital cellular components [19-21]. Their implication in the pathogenesis of numerous disease disorders, together with diabetes, cardiac diseases, respiratory disorders, neurodegenerative conditions, cancers, cataract progression, and rheumatoid arthritis, underlines the serious necessity for attentive scientific inquiry into their extenuation strategies [23-25]. *Pleurotus* species has been successfully revealed to highlight certain therapeutic, biotechnological, and nutritional latent in fighting against such health challenges [26]. Moreover, factors persuading the production of *Pleurotus* species have been broadly pondered [27]. Recent studies have explored the bioactivities of polysaccharides derived from *Pleurotus* species and the advancement of innovative extraction procedures [28]. However, there remains a conspicuous gap in the literature regarding comprehensive reviews elucidating the antioxidant proficiency of *Pleurotus* extracts in scavenging free radicals.

2. NUTRITIONAL PROPERTIES OF OYSTER MUSHROOMS

Oyster mushrooms play a pivotal role of nutritional powerhouse, boasting a rich conformation that enables them a valued addition to any diet. Plentiful in protein, carbohydrates, and vitamins, their nutrient profile fluctuates somewhat depending on the specific species. However, across the panel, Oyster mushrooms are prominent for their remarkable protein content, reflecting them an exceptional choice for those seeking alternative sources of this essential macronutrient, predominantly for vegetarians. Besides, their low-fat content further augments their dietary demand, placing them as an extremely desirable food for individuals targeting to maintain a balanced and healthy diet. Whether incorporated into savoury dishes or utilized as a meat auxiliary, the nutritional density of Oyster mushrooms underscores their potential to contribute to overall health and well-being, offering a justifiable and wholesome option for those seeking to heighten their nutritional intake.

Carbohydrate: The fruiting body of mushrooms aids as the primary reservoir for carbohydrates, encompassing a substantial portion of the total carbohydrate content within the organism. Studies conducted in last decade sought to elucidate the carbohydrate conformation of many Oyster mushroom species, including *Pleurotus florida*, *Pleurotus ostreatus*, and *Pleurotus sajor-caju* [2,29]. The findings revealed noteworthy disparities in carbohydrate content among these species, with *Pleurotus eryngii* emerging as the front-runner, boasting a remarkable carbohydrate concentration of about 40g per 100g of mushroom. Following closely behind, *Pleurotus sajor-caju* showed a considerable carbohydrate presence, comprising 38g per 100g of mushroom biomass. These annotations underscore the changeability in carbohydrate conformation among different Oyster mushroom strains, highlighting the potential for targeted cultivation strategies to improve carbohydrate yield for several applications in nutrition, biotechnology, and pharmaceuticals. Besides, the studies along these notions and objectives provide clues to design new formulae for commercial supplementation [6,30].

Protein: Protein constitutes a vital constituent of mushroom dry weight, incomparable protein content characteristically found in vegetable sources. Edible mushroom proteins are high in quality, low in cost, widely available and meet environmental and social requirements, making them suitable as sustainable alternative proteins [31,32]. Remarkably, mushrooms emerge as a significant protein source, offering a worthwhile alternative to animal-derived meat products because of their provision of essential amino acids, a symbolic feature shared with animal protein sources [2]. Indeed, mushrooms have gathered attention as a treasured dietary supplement, predominantly for individuals adhering to vegetarian diets [33]. Fascinatingly, the total nitrogen content of mushrooms predominantly derives from proteinaceous amino acids, constituting around 80% of the crude protein value relative to the ideal protein standard of 100% [34,35]. Such insights underscore the nutritional worth of mushrooms as protein pools, strengthening their appeal as justifiable and nutritious dietary components in the pursuit for heightened health and dietary diversity.

Fats: Mushrooms, well-known for their nutritional prosperity, display a distinguishing lipid profile branded by a lower fat concentration relative to their protein and carbohydrate content. Though, the fats they do contain are principally comprised of unsaturated fatty acids, stressing their potential health-promoting possessions. In spite of their modest fat content, Oyster mushrooms, a prominent species within the fungal kingdom, feature linoleic acid as their prime fatty acid. The lipid profile across mushroom species can vary meaningfully, ranging from 0.2 to 8 grams per 100 grams of dry fruit bodies. A seminal study focused on three species of *Pleurotus* mushrooms, revealing intriguing insights into their lipid content. Among the species examined, *Pleurotus sajor-caju* emerged with the highest lipid content, at 0.61 grams per 100 grams of the fruiting body, followed by *Pleurotus ostreatus* (0.53 grams) and *Pleurotus florida* (0.46 grams) [29,36].

Vitamins: Mushrooms stand renowned for their remarkable vitamin content, standing as exemplary sources of essential nutrients, particularly Vitamin B [37,38]. Remarkably, while mushrooms commonly contain modest amounts of vitamin C, their significance is further underscored by the exposure that wild varieties boast considerably higher levels of vitamin D2 compared to their commercially cultivated counterparts, such as the commonly consumed *A. bisporus* [39]. This revelation underscores the potential of mushrooms as a natural source of vitamin D, mostly crucial for individuals with restricted exposure to sunlight or dietary sources of this essential nutrient. As such, mushrooms arise as crucial constituents of a balanced diet, offering a rich source of vitamins essential for human health and well-being.

3. THERAPEUTICS OF THE OYSTER MUSHROOMS

The term "therapeutics" encapsulates the multifaceted domain of medicine concerned with the treatment of diseases, while the concept of a drug's therapeutic value delineates its efficacy in eliciting desired physiological responses upon administration [40]. In contemporary discourse, the paradigm of therapeutic interventions has expanded beyond conventional pharmaceuticals to encompass a diverse array of foods meticulously crafted to deliver therapeutic benefits. Among these, whole foods such as nuts, seeds, fruits, vegetables, whole grains, cruciferous vegetables like broccoli, cabbage, cauliflower, antioxidant-rich berries like cranberries, omega-3 fatty acid-rich fish, flaxseeds, garlic, adaptogenic herbs like ginseng, oats, polyphenol rich red grapes and red wine in moderation, soybean, and lycopene specked tomatoes have garnered particular attention for their potential therapeutic properties [41]. However, amidst this burgeoning landscape of therapeutic foods, caution must be exercised, especially in the case of wild mushrooms. While certain mushrooms hold esteemed positions in traditional medicine and culinary traditions, not all varieties found in the wild are safe for consumption. Indeed, some contain compounds that pose significant health risks if ingested. Hence, prudent consumption dictates adherence to the classification of safe-to-eat mushrooms. Oyster mushrooms stand out in this regard, characterized by their safety profile and ease of cultivation. Renowned for their versatility in culinary applications, Oyster mushrooms also harbour a plethora of therapeutic effects, making them an invaluable addition to the armamentarium of functional foods aimed at promoting health and well-being [42,43].

4. ANTIBIOTIC EFFECT

In a groundbreaking study, researchers investigated the antibiotic potential of extracts derived from various strains of Oyster mushrooms (*Pleurotus eryngii* var. eryngii, *P. eryngii* var. ferulae, *P. eryngii* var. *elaeoselini*, and *P. nebrodensis*) against a panel of reference bacterial strains including *Staphylococcus* *aureus*, *Staphylococcus epidermidis*, *Pseudomonas aeruginosa*, and *Escherichia coli* [44]. The results exposed varying degrees of antibacterial activity across the mushroom strains, highlighting their potential as natural antimicrobial agents. Moreover, another group of researchers explored the antibacterial efficacy of *P. florida* extracts against bacterial and fungal pathogens, demonstrating significant inhibitory effects, particularly with the ethanolic extract exhibiting promising minimum inhibitory concentrations against *Escherichia coli* and other pathogens. Further investigations into the bioactive constituents of Oyster mushrooms, such as phenolic and tannin compounds found in *P. ostreatus*, elucidated mechanisms of action including cell membrane lysis, inhibition of protein synthesis, and interference with microbial adhesion processes [45]. Remarkably, petroleum and acetone extracts of *P. ostreatus* exhibited broad-spectrum antibacterial activity against both gram-positive and gram-negative bacteria, offering potential solutions to combat the rising threat of multidrug-resistant pathogens. These findings underscore the importance of exploring natural sources like Oyster mushrooms for novel antibiotic therapeutics in the face of intensifying antimicrobial resistance [44,45].

5. ANTIVIRAL EFFECT

In the quest of effective antiviral chemotherapy, the supreme objective is to recognize agents that selectively obstruct viral replication. Fungi represent a vast source of bioactive molecules, which could potentially be used as antivirals in the future [46]. Potential research study has made a significant pace in this endeavour through isolating and characterizing a purified laccase enzyme derived from the *P. ostreatus* mushroom. These efforts revealed the remarkable capability of this laccase in inhibiting the entry of the hepatitis C virus into both peripheral blood cells and hepatoma HepG2 cells, as well as suppressing its replication. This innovative finding underscores the potential of natural compounds, such as those found in mushrooms, as promising candidates for antiviral therapeutics, offering a beacon of hope in the ongoing battle against viral contagions [47,48].

6. A SOURCE OF ANTIOXIDANT

Antioxidants play a critical role in mitigating oxidative stress within cells, counteracting the harmful effects of reactive oxygen species (ROS) such as superoxides, peroxides, and hydroxyl radicals. Left unchecked, ROS can inflict oxidative damage on cellular structures, contributing to the development of degenerative diseases like cancer and hepatotoxicity [49,50]. *Pleurotus* species, commonly known as oyster mushrooms, emerges as a potent source of antioxidants, offering a natural solution for disease prevention and treatment [51,52]. Studies have demonstrated the longevity-promoting effects of *Pleurotus* species antioxidants in organisms like the Mexican fruit fly *Anastrepha ludens* [51,53]. The vitamin and selenium contents inherent in *Pleurotus* species further augment its antioxidant properties. Research by Jayakumar *et al.* [54] emphasized the ability of *Pleurotus ostreatus* extracts to upregulate catalase gene expression in aging rats, protection against age-linked oxidative stress. Additionally, water-soluble crude polysaccharide extracts from *P. ostreatus* have unveiled notable antioxidant abilities, as proved by their potent free radical scavenging and nitric oxide synthase activation possessions. Remarkably, an acidic polysaccharide isolated from *Pleurotus ostreatus* has demonstrated robust antioxidant effects, underscoring the potential of *Pleurotus* species as a treasured source of antioxidants for combating oxidative stress-related diseases [55-57]. As an outcome, mushrooms have evolved a preventive structure comprising of high concentrations of antioxidants such as selenium, polyphenols, β-glucans, ergothioneine, various vitamins and other bioactive metabolites [58].

7. ANTITUMOR AND ANTICANCER ACTIVITY

Pleurotus species have gathered significant attention in the area of cancer research because of their inherent tumor-suppressing possessions, a phenomenon well-documented over a prolonged period. While several extracts from diverse *Pleurotus* species have confirmed anti-cancer activity in both cancer cell lines and experimental animal models, the translation of these findings into clinical practice through human trials remains lacking [59,60]. Remarkable annotations include the capability of hot water extracts of *Pleurotus* species to inhibit the spread of MCF-7 human breast cancer cells. Furthermore, treatment with *P. ostreatus* extracts has been shown to down regulate the expression of key biomarkers associated with colon cancer, such as cyclin D1 and Ki-67 [31]. Subsequent studies on antitumor potential of *Pleurotus* species by validated these findings, representing the efficacy of hot water and ethanol extracts from *Pleurotus* fruiting bodies against various human solid carcinomas, including lung and cervical carcinomas [61,62]. The immune-modulatory role of *Pleurotus ferulae* polysaccharides (PFPS) was further elucidated, enhancing the therapeutic effectiveness of dendritic cell-based vaccines targeting human papilloma virus. These altogether findings highlight the promising latent of *Pleurotus* species as treasured additions to the armamentarium of cancer therapeutics, necessitating further exploration and clinical validation [63].

8. MYCO-REMEDIATION

Myco-remediation, the process through which fungal species are employed for bioremediation drives, has gathered substantial attention in environmental science and biotechnology. Fungi, owing to their flexible metabolic capabilities, have arisen as promising agents for combating environmental pollutants. Among these fungi, oyster mushrooms have demonstrated notable bioremediation capabilities [64]. *Pleurotus pulmonarius* is identified as an effective fungus in degrading crude oil, offering a natural solution to oil spill remediation efforts [65]. Moreover, the efficacy of *Pleurotus pulmonarius* is successfully confirmed in combating radioactive cellulose-based waste, signifying its worth in nuclear waste management [66]. Spent Mushroom Compost (SMC) has arisen as a treasured resource in myco-remediation, with studies by Law *et al.* revealing the capacity of *Pleurotus pulmonarius* SMC to significantly reduce pentachlorophenol (PCP) levels [67]. Furthermore, myco-remediation encompasses to bio-absorption, with research representing the ability of several oyster mushroom species, together with *Pleurotus ostreatus*, *Pleurotus sajor-caju*, and *Pleurotus florida*, to absorb heavy metals such as cadmium, lead, copper, and chromium from contaminated substrates [68]. These findings highlight the multifaceted potential of Oyster mushrooms in environmental remediation approaches, offering maintainable and eco-friendly solutions to various pollution challenges. The use of Oyster mushrooms is considered a sustainable strategy in the bioremediation of polluted environments, the biodegradation of agro-wastes or agro-industrial wastes, and the bio-fermentation of ligninolytic wastes to produce enzymes. Beyond their nutritional benefits, Oyster mushrooms play a crucial role in sustainable agriculture, as they can be cultivated using various waste materials, such as agricultural residues and sawdust, reducing the strain on traditional farming resources. Their rapid growth and ability to break down organic matter also make them valuable decomposers in ecosystems [69].

9. CONCLUSION AND FUTURE PERSPECTIVES

The exploration of *Pleurotus ostreatus*, a remarkable edible mushroom boasting both nutritional and biomedical significance, reveals a rich reservoir of bioactive compounds with diverse therapeutic functions. These compounds hold immense promise in addressing a myriad of health conditions. Furthermore, owing to its exceptional nutritional profile, *Pleurotus ostreatus* stands as a potentially in the fight against malnutrition-related diseases, offering a natural and sustainable solution. However, the current focus of research predominantly revolves around extracts derived from the fruiting body, with comparatively fewer studies investigating extracts from cultivated fungi. Hence, there exists a compelling need to redirect research efforts towards exploring the therapeutic potential inherent in cultivated strains. Despite the wealth of *in vivo* and *in vitro* evidence supporting the therapeutic effects of *Pleurotus ostreatus*, the translation of these findings into clinical practice necessitates rigorous clinical trials. Furthermore, mushrooms may be safe as a vaccine adjuvant, but there is mild concern about using them to treat people with for example active SARS-CoV-2 infection since an immune-stimulating agent like mushroom might supercharge an individual's immune response, leading to a cytokine storm, posing the greater risk of COVID-19 mortality [37]. New efforts are needed to elucidate the still unknown bioactive compounds present in different mushrooms and their therapeutic potential. Novel toxicological studies are needed to ensure their safety and promote pre- and clinical studies. Therefore, future research endeavours should prioritize clinical investigations to fully elucidate the therapeutic spectrum and unlock the vast potentials of this remarkable mushroom species.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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