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A Review on Benefits, Cultivation and Biodiversity of Macrofungi

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ABSTRACT

Worldwide, macrofungi production as well as their economic value have been rising steadily. Due to their multiple health advantages and abundance of nutrients, functional foods, dietary supplements, and traditional medicines made from macrofungi are becoming more and more popular However, only a few bioactive macrofungus-derived products have been made commercially available. As a result, it is imperative to create a practical, high-yield macrofungus cultivation method to meet demand and customer expectations. There is an urgent need for efficient solutions to the problem because most macrofungal resources have not yet been properly researched, implemented and because macrofungi are varied with difficult and highly changeable development circumstances. This review is of great importance as it comprehensively state the cultivation strategies , current developments in the production of newly discovered bioactive components of Macrofungi .Furthermore, the creation of macrofungal foods is explored in order to change the nutritional value of food and its quality attributes.

Keywords: Macrofungi,Bioactive compound, Nutraceutical, Cultivation Technology, Nutritional and Therapeutic Application

INTRODUCTION

Macrofungi are a group of fungi characterized by their large, spore-bearing structures that are easily visible. These fungi are heterotrophic organisms belonging to the kingdom of fungi and are classified under the phyla Basidiomycota and Ascomycota (Kinge et al., 2020).

Figure 1. Kingdom Fungi. (Govorushka et al., 2019)

Within the Fungal kingdom, macrofungi, including those from the phyla Basidiomycota and Ascomycota, exhibit distinct morphological differences in their above-ground (epigeous) or below-ground (hypogeous) fruiting bodies (Govorushko et al., 2019). Globally, approximately 14,000 different species

of macrofungi have been discovered. Among them, more than 2,000 species are recognized for their edibility and/or therapeutic properties (Meenu et al., 2019).

Macrofungi, aside from their role in providing a wide range of ecosystem services, also offer innovative applications in biotechnology, medicine, and ecology. They have a versatile range of uses in various fields (Niego et al., 2021).

Macrofungi find applications as pharmaceutical products, commercial nutraceuticals, and as flavorful, nutrient-rich culinary ingredients. Their bioactivity and distinctive flavors make them valuable. Notably, *Lentinus edodes* (shiitake) and *Pleurotus* spp. (oyster mushrooms) are among the most widely cultivated and popular edible macrofungi (Bellettini et al., 2019).

The harvesting of wild-crafted macrofungi and the artificial cultivation of macrofungi using natural resources are susceptible to contamination by radionuclides and toxic metals like cadmium (Cd), lead (Pb), mercury (Hg), silver (Ag), and arsenic (As) due to increasing environmental pollution. This highlights a significant concern for the safety of these resources (Brzezicha-Cirocka et al, 2019). Cooking has a notable effect on reducing the levels of arsenic (As) in macrofungi, with reductions ranging from 26% to 72%. However, it has a comparatively smaller impact on the levels of mercury (Hg), cadmium (Cd), and lead (Pb) in these fungi (Chiocchetti et al., 2020).

The development of alternative culture media and techniques with specific safety measures could help address this issue. In recent years, the emergence of submerged culture for macrofungi has brought significant advantages compared to traditional solid cultures. These advantages include faster incubation times, easier control over culture conditions, and immediate access to active metabolites and specific culture components (Lu et al., 2020). Submerged cultivation of macrofungi may indeed result in increased levels of bioactive chemicals that can be derived from these fungi. This method offers a promising avenue for obtaining higher concentrations of beneficial compounds from macrofungi (Rathore et al.,2019).

Numerous health-enhancing products derived from macrofungi are now accessible in various forms such as tablets, capsules, syrups, pastes, and powders within the market. This expansion is driven by the myriad health advantages and nutritional value provided by macrofungi, leading to their increased utilization in functional foods, dietary supplements, and traditional medicinal applications (Azeem et al., 2020).

Many significant macrofungi, including popular edible mushrooms like *Tricholoma matsutake* and valuable medicinal fungi like *Ophiocordyceps sinensis*, have seen a substantial decline in their populations. This is a concerning development, especially considering their importance for both culinary and therapeutic purposes (Cao et al., 2021).

Mushrooms have been cherished for generations as traditional sources of bioactive natural compounds and as promising therapeutic agents. Research into medicinal mushrooms has unveiled a wide range of unique physiologically active substances with potential health benefits (De Silva et al., 2013).

Due to the limited exploration and utilization of macrofungal resources, coupled with the diversity and complex development conditions and bioactive elements found in macrofungi, there is a pressing need for effective solutions to address this issue (Lu et al., 2020).

THE LITERATURE REVIEW

Benefits of Macrofugi

Nutraceuticals

Wild edible mushrooms share a special place in the past and modern deitic regimen because of nutritional and nutraceuticals potential. They contain many unexplored source of bioactive components, and, with the passage of comprising unlimited untapped sources of bioactive components. The ethno-mycological data surveyed on these wild mushrooms reveals that fruiting bodies can be consumed and will have good effect on the health of the individuals. Ethno-mycological data collected on these wild mushrooms indicates that consuming their fruiting bodies can positively impact individuals' health(Thakur ,2019).

Mushrooms are considered an ideal dietary food due to their abundance of essential nutrients, offering high nutritional value. In addition to their nutritional benefits, these fungi have the potential to function as immunomodulators, anticancer agents, antiviral substances, antioxidants, and anti-inflammatory remedies, among other therapeutic effects (Sharma et al., 2023).

Medicinal macrofungi refer to species that produce secondary metabolites with a range of biological functions. Out of the roughly 270 mushroom species known for their therapeutic properties, only a small subset are recognized as nutraceuticals. The following species are most commonly found in dietary supplements: *A. bisporus* (button mushroom), *O. sinensis* (cordyceps), *G. lingzhi* (Reishi), *Grifola frondosa* (maitake), *Hericium erinaceus* (lion's mane), *L. edodes* (shiitake), and *Trametes versicolor* (turkey tail) (Niego et al., 2021).

The compounds extracted from mushrooms, such as *Agaricus blazei*, have shown the potential to treat conditions including cancer, arteriosclerosis, hyperlipidemia, chronic hepatitis, and diabetes. Their therapeutic significance for public health is significant. Furthermore, medicinal mushrooms can be applied in the treatment of chronic catarrh, breast-related issues, and joint ailments in general (Onifade, et al., 2023).

Nutritional value

For centuries, people have utilized wild macrofungi for sustenance and healing. They are often termed "vegetarian meat" due to their substantial protein, carbohydrate, and low fat content when compared to other grains, legumes, fruits, and vegetables. Mushrooms, in particular, boast a protein content typically ranging from 20% to 35% of their dry weight. (Gogoi et al., 2023)

Macrofungi hold significant promise as sources of physiologically active natural compounds with both medicinal and nutritional advantages.Additionally, the study tested the ethanol:water (70:30) extract of wild basidiomata for its antioxidant, antibacterial, and cytotoxic properties (Giraldo et al.,2023).

A variety of nutrients are provided by eating mushrooms, including carbohydrates (such as sucrose, xylose, rhamnose, mannose, and fructose), amino acids (such as glutamate, aspartic acid, and methionine), proteins, fatty acids (such as linoleic acid, stearic acid, palmitic acid, adrenic acid, and nervonic acid), vitamins (such as folate, riboflavin, ascor bic acid, niacin, thiamine, ergocalciferol, and cyanocobalamine), mineral contents (including calcium, magnesium, potassium, phosphorus, sodium, iron, copper, zinc, cadmium, and molybdenum), and phenolic compounds (like gallic acid, caffeic acid, protocatechuic acid, p-coumaric acid, p-hydroxybenzoic acid, and pyrogallol). These substances regulate a variety of biological functions and lower the risk of certain chronic diseases, which helps to maintain good health (Das & Prakash et al., 2022).

Bioactive Macrofungi Compounds and Their Therapeutic Properties

Species of Mushrooms that Contain Bioactive Polysaccharides

Polysaccharides, found in mushrooms, are the most powerful components responsible for a diverse range of physiological functions. These functions include anticancer, immunomodulatory, antioxidant, antiviral, anti-inflammatory, anticarcinogenic, and neuroprotective effects. In macrofungi, biologically active polysaccharides, often in the form of glucan derivatives, exhibit a wide range of forms and characteristics (Niego et al., 2021).

Table 1. Lists of some important macrofungi and the bioactivities of polysaccharides from experimental studies (Niego et al., 2021) .

Macrofungal Species	Bioactivity
Agaricus bisporus	Improve serum enzyme activities, biochemical levels, lipid contents, and antioxidant status to protect hepatic and renal functions as well as to have antiaging properties.
Ganoderma spp	very promising nutraceuticals that have a variety of bioactivities, including anti-angiogenesis, antidiabetic, antioxidant, antiproliferative, hepatoprotective, and immunomodulatory.
Grifola frondosa	very promising anticancer medications. In actuality, a G. A medication made from frondosa polysaccharides was created in China and given approval as an additional therapeutic medicine for the treatment of cancer.
Lentinula edodes	Demonstrate anticancer efficacy against HeLa cells from human cervical cancer, inhibiting their proliferative ability and inducing apoptosis.
Ophiocordyceps sinensis	a highly promising source of bioactive polysaccharides that have antioxidant, anti-inflammatory, anti-cancer, anti-hypertensive, anti-obesity, and anti-inflammatory properties, as well as the ability to deliver drugs. They can also act as prebiotics.
Pleurotus eryngii	Inhibit the growth of HepG-2 human hepatoblastoma cells.
Pleurotus ostreatus	Possess more varied bioactivities. The hypoglycemic, hypolipidemic, and antioxidant effects of P. ostreatus have been studied extensively in animals.
Trametes versicolor	Exhibited a wide range of bioactivities as well, particularly against various cancer types.

Macrofungal β-glucans

Mushroom β-Glucans are recognized for their dual ability to serve as immunostimulants and immunosuppressants. They are particularly notable for their anti-inflammatory, anticholesterolemic, diabetes management, mycotherapy, and potential use as adjuvants in COVID-19 vaccines (Timm et al., 2023).

Research on β-glucans has revealed their positive impact on human well-being. These compounds are responsible for a wide range of bioactivities, including immunomodulation, improvement of lipid balance, anticholesterolemic effects, antidiabetic properties, antioxidant activity, and neuroprotection. Additionally, they have a significant influence on the overall well-being of theconsumer (Niego et al., 2021).

Macrofungal Development

Food product

In recent years, both the global economy and mushroom production have seen steady growth. Macrofungi are increasingly used as functional foods, nutritional supplements, and traditional medicines due to their wealth of nutrients and various health benefits (Selem et al., 2021).

Table 2. Macrofungus-based food products

Macrofungus	Food Products	Effect And Result	References
Mycelia of Antrodia camphorata, Agaricus blaze, Hericium erinaceus, and Phellinus linteus	Bread	Elevated umami potency, preservation of considerable quantities of GABA and ergothioneine.	(Ulziijargal et al., 2013)
Pleurotus sajor-caju fruiting body	Biscuit	Enhanced levels of dietary fiber, alpha-glucan, and protein in the biscuit to better regulate post-meal blood sugar levels.	(Ng et al., 2017)
Lentinus edodes	Rice noodle	Enhance the stretchiness and firmness of rice noodles.	(Stephan et al., 2018)
Pleurotus sapidus	Vegan sausage	Substitute for commercially available vegetable protein sources.	(Stephan et al., 2018)
Grifola frondosa, Ganoderma lucidum	Fermented tea	Enhance the sensory taste and therapeutic attributes of fermented tea.	(Terrien, 2017)

For centuries, humans have relied on macrofungi as a nutritional source, sig nificantly enhancing human health. The global production, trade, and consumption of these fungi have surged dramatically due to their recognized value as a vital food source (Mortimer et al.,2021).

Utilizing mycelia and fruiting bodies of macrofungi in innovative ways enhances both food flavor and nutritional content. This approach has the potential to elevate the industrial value of macrofungi, all while ensuring consumer acceptance (Rathore et al., 2019).

Adding *Agaricus bisporus* polysaccharide to gluten-free flours enhanced the functional, pasting, rheological, and sensory qualities of both flour and biscuit doughs. This improvement renders these products suitable for consumption by individuals with celiac disease (Sulieman,et al., 2019).

Safety issues with the production and consumption of macrofungi

The majority of macrofungi are edible or have medicinal properties, but some species are toxic, resulting in fatal incidents annually. The poisoning of macrofungi in humans has been documented since ancient times, as seen in ancient texts like the "Rigveda" (circa 3500 B.C.) and the "Atharvaveda" (circa 1500 B.C.). Lack of knowledge, misidentification, and failure to avoid toxic species can result in various health risks, including vomiting, nausea, stomachache, gastroenteritis, diarrhea, hepatotoxicity, nephrotoxicity, neurotoxicity, rhabdomyolysis symptoms, erythromelalgia syndrome, and, in some cases, even mortality (Azeem et al. , 2020).

Cultivation

Artificial Macrofungus cultivation

Mushrooms, edible fungi suitable for people of all ages, offer abundant high-quality food with a high biological value, grown on various substrates. Rich in all essential amino acids, mushrooms provide a protein-rich, low-calorie diet, making them ideal for heart patients. Oyster mushrooms, among the diverse mushroom varieties, are commonly cultivated (Nongthombam et al., 2021).

Recent studies have shown that cultivating macrofungi in shaded forest environments enhances soil biological activity, improves soil aeration, preserves soil structure, balances soil nutrients, and alters bacterial species through hyphal extension (Liu et al., 2021).

Submerged cultivation, a recent advancement in macrofungi technology, offers several advantages over traditional solid culture methods. These include a brief incubation period, precise control of culture conditions, and easy access to active metabolites and specific culture components (Lu et al., 2020).

Spawning Techniques

In the context of mushroom cultivation, the term "spawn" refers to a mushroom species' mycelia that have been embedded in a seed substrate. It acts as the inoculum for mushroom cultivation. The number and quality of the eventual mushroom yield are significantly influenced by the quality of the mushroom spawning. For successful mushroom production, healthy, white spawns are preferable since preserving purity is crucial to preventing infection by bacteria, fungus, and viruses. Reduced yields can result from contaminants that coexist with spawning. Therefore, it's crucial to use the right procedures for spawn preparation in order to guarantee a good harvest (Thakur et al., 2022).

Biodiversity

Macrofungi are considered non-timber forest inhabitants essential for the environment. They play a crucial role as significant decomposers of forest litter and organic matter, ensuring soil fertility. Additionally, they serve as essential partners for various species through mycorrhizae, forming symbiotic relationships with trees (Dulay et al., 2020).

Deadwood is vital for maintaining forest ecosystem diversity. Ecologists and conservationists often use its quantity and quality as a close indicator of forest biodiversity (Jaroszewicz et al. ,2021).

The heterotrophic group of organisms known as fungi includes both single-celled and multicellular species. The global number of fungi has been estimated by various researchers. Bishy and Ainsworth reported around 100,000 different fungal species, while Hawksworth suggested there are 1.5 million species

worldwide. The total estimated number of fungi ranges from 3.5 to 5.1 million, making fungi the second largest biotic community after insects. Among the 149,974 recognized species of these organisms, 41,000 macrofungi species are currently identified, having ancestry from both basidiomycetes and ascomycetes (Zeb et al., 2023).

Macrofungi exhibit diverse structures and reproductive methods, and they can be discovered in various environments across the world's ecogeographic zones (Azeem et al.,2020). While factors like canopy gaps, basal area, and stand age played roles, the study highlighted that deadwood volume, tree species, and decay stage were the main influencers of fungal species richness and the presence of fungi on the red list. Lying coarse deadwood showed the highest species richness, while standing coarse woody debris and fine deadwood had lower species densities (Atrena et al., 2020).

CONCLUDING REMARKS

Macrofungi have a large potential as research tools and have a wide variety of possible applications because of their abundance in nutrients and other bioactive components. Additionally, they can be utilised to support conventional pharmaceutical therapy and aid people who aren't candidates in delaying the onset of chronic illnesses. The development of macrofungal products, the expansion of the supply chain, and the benefits that eating mushrooms has on your health have all contributed to their expanding market value. Growing mushrooms completely depends on the environment. In order to prevent infection, the area where it is grown and the room must be properly sterilized. The macrofungi biotic community is enormous as it is the second-largest biotic community after insects, and it may grow much more in the coming years as macrofungi study expands.

RECOMMENDATIONS

Due to their significance in the food, pharmaceutical, biocontrol, chemical, and biological sectors, macrofungi are significant economically. Although macrofungi are an essential component of a particular ecosystem, little is known about their diversity and varieties. One of the best recommendations is to conduct additional research to better understand the ecology and distribution of macrofungi and pinpoint regions with a high biodiversity. As the demand of pharmaceutical benefits of macrofungi ,the supply of macrofungi will upsurge too .Macrofungi takes several weeks to months to mature , Enhancing the cultivation of macrofungi is the best solution . According to studies ,Submerged cultivation has numerous advantages over conventional solid culture , So recommending continuously innovate and experiment with new cultivation techniques and technologies to improve yields ,quality and sustainability .

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