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Mushrooms: Importance, Types, Production and Economics

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Abstract

Mushrooms represent an economically and biologically critical group of organisms within the kingdom Fungi, which comprises over 150,000 estimated species. Of these, approximately 14,000 to 22,000 produce macroscopic fruiting bodies. This review synthesizes current scientific literature regarding the nutritional, medicinal, ecological and industrial significance of mushrooms. We provide a taxonomic framework of major cultivated and wild species, detail global production systems and substrate biotechnology and analyse contemporary market economics. The global mushroom market was valued at roughly USD 33.2 billion in 2020 and is projected to exceed USD 86 billion by 2030, driven by a 9.5-10.8% compound annual growth rate (CAGR). With China contributing approximately 73% of the 10.5 million metric tonnes produced globally in 2021, the industry is scaling rapidly. High in protein (10-38% dry weight), immunomodulatory β -glucans and vital metabolites, mushrooms are critical to human health and nutrition. Furthermore, their ecological role as decomposers and their emerging industrial applications in mycoproteins and biodegradable packaging underscore their expanding value. This review highlights the necessity for further research, policy support and collaboration to maximize the potential of fungi in the circular bioeconomy.

Keywords: Mushroom cultivation, Fungal biotechnology, Medicinal fungi, Global mushroom market, β -glucans, *Lentinula edodes*, *Pleurotus ostreatus*, Mycoproteins, Bioeconomy, Substrate biotechnology

1. Introduction

The kingdom Fungi is one of the most ecologically vital and taxonomically diverse groups of life on Earth, containing an estimated 1.5 to 5.1 million species (Hawksworth and Lücking, 2017) ^[9]. Macrofungi, which are defined as organisms that yield visible fruiting bodies (sporocarps), comprise roughly 14,000 to 22,000 described species (Kirk *et al.*, 2008) ^[15]. Within this group, approximately 2,000 are identified as edible and nearly 700 are recognized for their pharmacological efficacy (Chang and Miles, 2004) ^[12]. The term "mushroom" commonly designates the sporocarps of macrofungi belonging to the phyla Basidiomycota and Ascomycota, including both industrially cultivated saprotrophic species and wild ectomycorrhizal species.

Human utilization of mushrooms is deeply rooted in history, with archaeological findings indicating consumption in Europe and Asia dating back at least 10,000 years. Historical Chinese texts from 206 BCE mention *Ganoderma lucidum* (Lingzhi) as a highly prized medicinal remedy (Wasser, 2002) ^[29]. The industrial cultivation era began in France around 1707 with the deliberate farming of *Agaricus bisporus* (button mushrooms) on horse manure beds. By the 20th century, advancements in fungal biology, substrate decomposition and environmental controls established the foundation for the modern global industry.

Today, mushroom science is driven by multidisciplinary applications:

- **Nutrition:** They provide umami-rich, high-protein, low-fat sustenance with a significantly lower environmental footprint than animal proteins.
- **Medicine:** Pharmaceutical applications, such as the immunomodulatory polysaccharopeptides lentinan, PSK and PSP, have been approved for cancer therapies in Asia.
- **Ecology:** Mycorrhizal networks facilitate critical nutrient exchanges across forest ecosystems.

- **Materials Science:** Biodegradable mycelium composites are replacing synthetic materials like polystyrene and leather.

2. Importance Of Mushrooms

2.1 Nutritional Significance

Mushrooms effectively bridge the dietary gap between plant and animal-derived foods. While species-specific, their macronutrient profile generally features high protein content (10-38% dry weight), minimal lipids (1-8% dry weight) and moderate carbohydrates primarily consisting of chitin, glycogen, trehalose and β -glucans (Mau *et al.*, 2001; Cheung, 2010) ^[18, 5].

The protein quality in species like *Pleurotus ostreatus* and *Lentinula edodes* is comparable to egg whites, scoring 0.63-0.90 on the protein digestibility-corrected amino acid score (PDCAAS) (Kalač, 2009) ^[11] and offering biologically significant concentrations of essential amino acids like lysine and leucine (Halliwell *et al.*, 2018) ^[8]. Mushrooms also provide dietary fibers that support probiotic gut health and cholesterol reduction. Notably, mushrooms are rich in ergosterol, a precursor to vitamin D₂ (Ooi and Liu, 2000) ^[21]. Post-harvest UV-B exposure can fortify mushrooms to provide 100% of the recommended daily intake of vitamin D₂ per 100 g of fresh weight (Cheung, 2013) ^[4]. They are also a primary dietary source of ergothioneine, a crucial antioxidant with cytoprotective properties (Keegan *et al.*, 2013) ^[13].

Table 1: Proximate nutritional composition of major commercial mushroom species (per 100 g dry weight). Values compiled from Mau *et al.* (2001) ^[18], Cheung (2010) ^[5] and USDA FoodData Central (2023).

Nutrient	<i>A. bisporus</i>	<i>P. ostreatus</i>	<i>L. edodes</i>	Unit (per 100g DW)
Protein	23.9-38.6	10.5-30.4	13.4-17.5	g
Carbohydrates	46.2-81.1	57.6-81.8	67.5-78.0	g
Crude Fiber	8.0-38.0	7.5-27.6	7.8-14.6	g
Fat	1.7-8.0	1.1-2.2	1.8-8.0	g
Energy	328-381	265-305	310-387	kcal
Vitamin D	0.1-31.9	0.5-29.0	0.1-4.0	μ g
Potassium	290-530	420-650	300-570	mg
β -glucan	2.4-7.0	14.5-30.0	3.9-18.7	g

2.2 Medicinal and Pharmacological Properties

Mushrooms contain diverse bioactive compounds, including glycoproteins, terpenoids and sterols, which exhibit antitumor, antiviral, antidiabetic and neuroprotective properties (Mori *et al.*, 2009) ^[19].

- **Immunomodulation and Anticancer Activity:** **Lentianan**, a β -glucan from *Lentinula edodes*, is approved in Japan as an adjunct immunotherapy for gastric, colorectal and breast cancers, significantly improving patient survival rates. Similarly, PSK (Krestin) from *Trametes versicolor* is a leading cancer drug in Japan (Zhang *et al.*, 2014) ^[31].
- **Neuroprotection:** *Hericium erinaceus* (Lion's Mane) contains hericenones and erinacines, which stimulate nerve growth factor (NGF) synthesis. Clinical trials show it improves cognitive function in patients with mild cognitive impairment and attenuates Alzheimer's pathology in preclinical models.
- **Adaptogenic Effects:** *Ganoderma lucidum* contains ganoderic acids that inhibit HMG-CoA reductase,

providing antihypertensive and hypolipidaemic benefits. *Cordyceps* species are utilized to improve aerobic capacity and fatigue resistance Chen *et al.* (2010) ^[3].

2.3 Ecological Importance

Fungi drive global carbon cycles, responsible for about 85% of organic matter mineralisation in forest soils (Baldrian, 2017) ^[1]. Ligninolytic species secrete extracellular enzymes that depolymerise lignin, releasing carbon and forming vital soil organic carbon stocks (Schlesinger and Bernhardt, 2013) ^[25]. Ectomycorrhizal (ECM) fungi form mutualistic networks with approximately 8,000 plant species, exchanging essential nutrients for photosynthetic carbon, dramatically improving forest productivity (Klupp *et al.*, 2015) ^[16]. Furthermore, fungi are highly effective in mycoremediation, utilizing their broad enzyme profiles to detoxify pollutants like heavy metals, diesel oil and microplastics (Rinaldi *et al.*, 2008) ^[22].

2.4 Industrial and Biotechnological Applications

Fungi are industrial powerhouses. For example, *Aspergillus niger* produces ~2 million metric tonnes of citric acid annually and white-rot basidiomycetes are evaluated for pre-treating agricultural residues for bioethanol production (Smith and Read, 2008) ^[26]. Mycelium-based composites are emerging as a revolutionary materials sector. Grown on agricultural waste, these composites match the tensile strength of polystyrene but biodegrade entirely within 30-90 days (Holt *et al.*, 2012) ^[10]. Fungal biomaterials are also being utilized in luxury fashion as a sustainable alternative to bovine leather.

3. Taxonomy and Major Cultivated Species

3.1 Taxonomic Framework

Macrofungi are predominantly classified into two phyla: Basidiomycota (~30,000 species) and Ascomycota (~65,000 species) (Olatunji *et al.*, 2018) ^[20]. Agaricomycetes, a class within Basidiomycota, includes most gilled mushrooms and polypores, while Ascomycota includes morels and truffles.

3.2 Major Commercially Cultivated Species

- ***Agaricus bisporus* (Button/Cremeni/Portobello):** The most cultivated globally (approx. 40% of world volume), grown on pasteurized composted manure. It requires strict climate control and a peat-limestone casing layer to trigger its biphasic lifecycle.
- ***Pleurotus ostreatus* (Oyster Mushroom):** Representing the fastest-growing sector, this highly efficient genus degrades lignocellulose, enabling cultivation on diverse agricultural by-products (straw, sawdust, coffee husks) with biological efficiencies (BE) of 80-150%.
- ***Lentinula edodes* (Shiitake):** The second most-consumed mushroom globally, grown traditionally on oak logs or in accelerated sawdust bags. It commands premium prices due to its umami profile and pharmaceutical properties.
- **Medicinal/Functional Species:** *Ganoderma lucidum* (Reishi) is heavily extracted for supplements, generating over USD 2.5 billion annually. *Cordyceps militaris* is valued for cordycepin, which modulates immune cytokines.

- **Wild and Ectomycorrhizal Species:** Truffles (*Tuber spp.*), porcini and chanterelles drive a USD 4.1 billion

global wild harvest market, with high-value truffles reaching up to USD 5,000/kg retail.

Table 2: Major commercially cultivated mushroom species: taxonomy, substrate preferences and biological efficiency. Compiled from Chang & Miles (2004), Stamets (2000) and FAO (2022).

Species	Common Name	Substrate	Yield (BE%)
<i>Agaricus bisporus</i>	Button / Cremini / Portobello	Composted manure	20-40
<i>Pleurotus ostreatus</i>	Oyster mushroom	Straw, sawdust	80-150
<i>Lentinula edodes</i>	Shiitake	Hardwood logs/sawdust	40-100
<i>Flammulina velutipes</i>	Enoki	Sawdust, rice bran	50-90
<i>Ganoderma lucidum</i>	Reishi / Lingzhi	Hardwood sawdust	10-30
<i>Hericium erinaceus</i>	Lion's Mane	Hardwood sawdust	30-60
<i>Tremella fuciformis</i>	Snow/White Fungus	Deciduous wood	20-50
<i>Volvariella volvacea</i>	Paddy Straw Mushroom	Rice straw	15-25
<i>Cyclocybe aegerita</i>	Black Poplar Mushroom	Various substrates	30-70
<i>Tuber melanosporum</i>	Black Truffle	Oak/Hazel roots	Inoculated trees

4. Mushroom Production: Systems And Biotechnology

4.1 Global Production Overview

Global mushroom production surged from 1 million metric tonnes (MT) in 1986 to an estimated 14.3 million MT in 2021. China dominates this landscape, producing ~73.0% (10,456,000 MT) of the world's supply in 2021, driven by a vast agricultural workforce, government-supported research and low-technology bag cultivation using abundant agricultural residues. Italy (~5.1%), the USA (~3.0%) and Poland (~2.5%) follow at a distance (FAO, 2022).

Table 3: World mushroom production by country (metric tonnes, fresh weight). Source: FAO FAOSTAT database (2022); * denotes estimated values.

Country	2015 (MT)	2018 (MT)	2021 (MT)	Share (%)
China	7,872,545	9,212,000	10,456,000	~73.0
Italy	789,100	750,000	731,000	~5.1
USA	391,100	412,000	430,000	~3.0
Poland	314,000	348,000	365,000	~2.5
Netherlands	290,000	305,000	310,000	~2.2
Spain	155,000	168,000	172,000	~1.2
India	115,000	130,000	158,000	~1.1
World Total	~10,000,000	~12,000,000	~14,300,000	100

4.2 Substrate Science and Biotechnology

Cultivation is fundamentally the bioconversion of lignocellulosic plant biomass into high-value protein. The optimal Carbon-to-Nitrogen (C: N) ratio for substrates is 20:1-40:1. Substrates undergo pasteurization, sterilization, or complex fermentation (composting) and are supplemented with agricultural by-products to modulate pH (6.0-7.5) and moisture (60-68%) (Khan *et al.*, 2018) ^[14]. Emerging biotechnologies include enzyme pre-treatments, cold pasteurization via alkaline lime treatments (reducing energy costs by 60-75%) and bio fermentation using suppressive *Bacillus subtilis* inoculants.

4.3 Spawn Production and Cultivation Infrastructure

Commercial spawn (mycelium) is propagated on sterilized grain or sawdust. High-tech farms utilize liquid fermentation spawn generated in bioreactors (50-1,000 L) for rapid, genetically homogenous colonization (Mane *et al.*, 2007) ^[17]. Cultivation occurs in tightly controlled indoor environments dictating precise temperature (± 0.5 °C), humidity and CO₂. Pests like sciarid flies and diseases such as *Trichoderma aggressivum* (green mould) are managed via strict Integrated Pest Management (IPM), including

HEPA filtration, biological control agents and precise farm hygiene (Sánchez, 2010) ^[24].

5. Economics Of The Global Mushroom Industry

5.1 Market Size and Growth

The industry is experiencing a massive boom due to health trends, urbanisation and clinical validations. In 2020, the edible mushroom segment was valued at USD 17.3 billion and functional/medicinal mushrooms at USD 8.1 billion. The global market is expected to reach USD 86-102 billion by 2030. The fastest-growing niche is mushroom-based meat alternatives (23.8% CAGR), pioneered by companies utilizing whole-cut mycelium products (Allied Market Research, 2023; Grand View Research, 2022).

Table 4: Global mushroom market segmentation by value (USD billions). Sources: Grand View Research (2021), Marketsand Markets (2022), Allied Market Research (2023). CAGR: Compound Annual Growth Rate 2020-2025.

Segment	2020 (USD B)	2025 Est. (USD B)	CAGR (%)
Edible Mushrooms (Fresh & Dried)	17.3	22.5	5.4
Functional / Medicinal Mushrooms	8.1	12.8	9.6
Mushroom Extracts & Supplements	5.2	9.4	12.5
Mushroom-based Meat Alternatives	1.1	3.2	23.8
Mycoprotein (Quorn <i>et al.</i>)	0.9	1.8	14.9
Spores / Spawn / Inoculants	0.6	1.0	10.8
Total Global Market	~33.2	~50.7	~8.8

5.2 Regional and Value Chain Economics

The Asia-Pacific (APAC) region controls ~78% of global market value, with China exhibiting the highest per capita consumption globally (>8 kg/year). Europe, led by the Netherlands and Poland, represents the second-largest market, notably shifting toward high-value specialty mushrooms. In developing regions like Sub-Saharan Africa and South Asia, low-tech oyster mushroom cultivation serves as an excellent rural poverty alleviation tool, increasing household incomes by 25-60% (Wipo, 2023) ^[30]. At the value-chain level, farm-gate gross margins vary from 15-25% for *A. bisporus* in Europe to 30-50% for fresh oyster mushrooms in Asia. Standardized medicinal extracts offer wholesale margins of 60-80%, commanding prices 15-30 times higher than fresh weight. Addressing the massive 25-40% post-harvest loss rate is a key economic focus, driving investments in cold-chain logistics, modified atmosphere packaging and vacuum drying.

Venture capital is aggressively funding mycelium innovations, with companies like Ecovative Design and MycoWorks raising tens to hundreds of millions for biomaterial development. Intellectual property protection for strains, substrates and extraction methodologies is highly active, with over 15,000 mushroom-related patents filed globally since 2000.

6. Challenges And Future Perspectives

The mushroom sector faces pressing challenges, particularly the impacts of climate change on the fruiting patterns of wild ectomycorrhizal species and the soaring energy costs of indoor climate-controlled cultivation (Kausrud *et al.*, 2012)^[12]. Substrate competition is intensifying as bioenergy and animal feed sectors vie for the same agricultural residues. A transition to circular urban farming models utilizing municipal organic waste presents a viable solution. Additionally, the standardization of bioactive content in dietary supplements remains a severe regulatory hurdle, necessitating precise HPLC quantification to prevent quality discrepancies. Future growth relies heavily on genomic frontiers, including CRISPR/Cas9 strain improvements for yield and stress tolerance and metagenomic discoveries from the rapidly expanding database of over 1,000 annotated fungal genomes.

7. Conclusion

Mushrooms represent a profound convergence of nutritional science, pharmacology, materials engineering and ecological sustainability. With a market poised to double within the decade, approaching a USD 100 billion valuation, they hold unique potential to address global challenges spanning food security, chronic disease and environmental degradation. To fully realize this potential, sustained international research, standardized regulatory frameworks and equitable technology transfer to developing economies are imperative. The kingdom Fungi is positioned to be a cornerstone of the 21st-century circular bioeconomy.

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