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HIDDEN TREASURES OF THE FORESTS: MANAGEMENT, ECONOMIC POTENTIAL, AND SUSTAINABLE USE OF EDIBLE MUSHROOMS

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Abstract

Globally, edible mushrooms from forests, which are regarded as one of the main non-wood forest products, have a significant contribution to food security and livelihoods. The aim of this study was to bring attention to the widespread edible mushrooms, by highlighting their country-level perspectives in countries with great tradition in terms of harvesting and the environmental and economic drivers of their productivity. A bibliometric analysis was performed on published papers in Web of Science and Scopus databases, and by using Microsoft Excel and VOSviewer software. A total of 873 articles published since 1975 in 327 academic journals were considered. Journal of Ethnobiology and Ethnomedicine, Environmental Science and Pollution Research, Journal of Fungi, and Mycoscience were the journals with the highest number of published papers. The results of the bibliometric analysis highlighted the worldwide interest in the management of wild edible mushrooms and their ecological and economic importance, on one hand and the need of sustainable use and regional conservation strategies, on another hand.

***Key words**: edible mushrooms, fungal resources, fungi, mushroom diversity, non-wood forest products.*

INTRODUCTION

Non-wood forest products (NWFPs), also referred to as non-timber forest products (NTFPs) have a globally substantial contribution in terms of supporting rural communities by enhancing overall livelihood (Akomaning et al., 2023; Huber et al., 2023; Dincă et al., 2025).

Wild mushrooms, one of the most important NTFPs worldwide, are a valuable resource for humans, even if many of them are very perishable (Bonciu et al., 2021).

They have been used for centuries as a food source and for their medicinal properties (Vamanu et al., 2023; Yilmaz, 2024).

Of the approximately 16,000 recognized edible mushroom species (Liu et al., 2022), around 2,200 are considered safe for human consumption (Boa, 2004; Li et al., 2021).

Their nutrient compounds are considered healthy, low calory, no glucose, low glycemic index and glycemic load, vegetable proteins, high dietary fibers, minerals, vitamins, and other useful bioactive compounds (Popa et al., 2016; Araújo-Rodrigues et al., 2024).

Wild and cultivated mushrooms are valuable resources to mitigate malnutrition and to ensure food security (Hait et al., 2025). It is expected that mushroom cultivation, by using agro-forestry waste materials, to become also a eco-friendly and profitable domain of the bio-circular economy (Ravlikovsky et al., 2024; Itubochi et al., 2025).

Wild mushrooms play a vital role in the forest and other natural ecosystems. Many form symbiotic (mycorrhizal) relationships with woody and grassy vegetation, while others function as saprotrophs, breaking down dead organic matter. Some species act as plant pathogens or exist as neutral epiphytes (Șesan et al., 2010; Șimonca et al., 2017; Mohali, 2023). All these species contribute to the great diversity of natural or anthropogenic (agriculture, urban/rural green zones, etc.)

ecosystems. Necrotrophic xylophagous mushrooms help create microhabitats in trees, supporting a high diversity of key bird species, such as woodpeckers (Ionescu et al., 2024).
At the same time, mushrooms, as non-timber forest products, enhance ecosystem services. Although their contributions, such as provisioning services (food, genetic resources, medicinal and ornamental uses) and regulating services (carbon sequestration, waste decomposition, detoxification, etc.), are significant, their full ecological role remains largely unexplored and not yet fully understood (Paula et al., 2025).
Local communities are interested in the quantity and diversity of mushrooms available on the market (Schunko et al., 2022). Crop-mushroom rotation has positive impact on soil quality, agricultural sustainability, and ecosystem health (Dou et al., 2025).
Environmental factors (climate, relief, soil, etc.) and biocenosis components (trees, shrubs, herbaceous plants) influence the availability of natural resources and consequently the distribution and productivity of the mushrooms (Herrero et al., 2019; Marin et al., 2022; Mustățea et al., 2022; Topa et al., 2024). It seems that climate change is influencing mushroom production (Kauserud et al., 2008; Kewessa et al., 2023), the invasive or introduced species distribution (Guo et al., 2017; Jacob et al., 2025).
The optimal management of resources, particularly of mushroom resources remains a topic of ongoing debate, shaped by the competing demands of human needs and the principles of nature conservation (Oprică et al., 2022; Tudose et al., 2023; Marin et al., 2024).
The aim of this paper was to deliver a systematic review of edible mushrooms from the forests over the 1975-2024 timeframe, using a bibliometric method, by highlighting the country-level perspectives and environmental and economic drivers of productivity of the most common edible mushrooms worldwide.

MATERIALS AND METHODS

The initial phase of this study consisted of a bibliometric analysis aimed at evaluating global scientific research on edible mushrooms from 1975 to 2024.
We conducted our analysis using the Science Citation Index Expanded (SCI-Expanded) within the Web of Science database (Clarivate, 2024), as well as Scopus (Scopus, 2025), to identify relevant publications.
After testing various search strategies and keyword combinations, the phrase *edible mushrooms in forest* was ultimately chosen as the primary search term.
The selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Page et al., 2021). An overview of the screening steps is presented in Figure 1.
A total of 692 publications were retrieved from Scopus database and 743 from Web of Science database, respectively. After removing 489 duplicate records, 946 papers remained for initial screening. Titles and abstracts were reviewed based on the following inclusion criteria: studies published in English and with titles and/or abstracts explicitly related to the topic. Exclusion criteria included: non-English publications, previous reviews, non-scientific articles, unpublished materials, and letters to the editor, respectively.
Following this manual screening, 23 sources were excluded, and 7 full texts could not be retrieved. The remaining 916 full-text articles were thoroughly reviewed. Of these, 39 were excluded for being unrelated to the topic, and 4 were removed due to the absence of an abstract. Therefore, 873 papers met the eligibility criteria and were included in this systematic review.
The bibliometric analysis examined several key dimensions: types of publications, research fields, publication years, contributing countries, leading authors, affiliated institutions, journals, publishers, and frequently used keywords, respectively. Data was processed using tools from the Web of Science Core Collection version 5.35, Scopus, Microsoft Excel version 2024 (Microsoft, 2024), and Geochart (Geochart, 2025). For visual mapping and cluster analysis, VOSviewer version 1.6.20 (VOSviewer, 2025) was employed.
The second phase of the study adopted a traditional literature review approach to provide an in-depth examination of the 873 selected articles. The results were organized into two thematic areas: (1) country-specific perspec-

tives, including diversity, uses, and ethnomycological knowledge; and (2) environmental and economic factors influencing wild edible mushroom productivity.

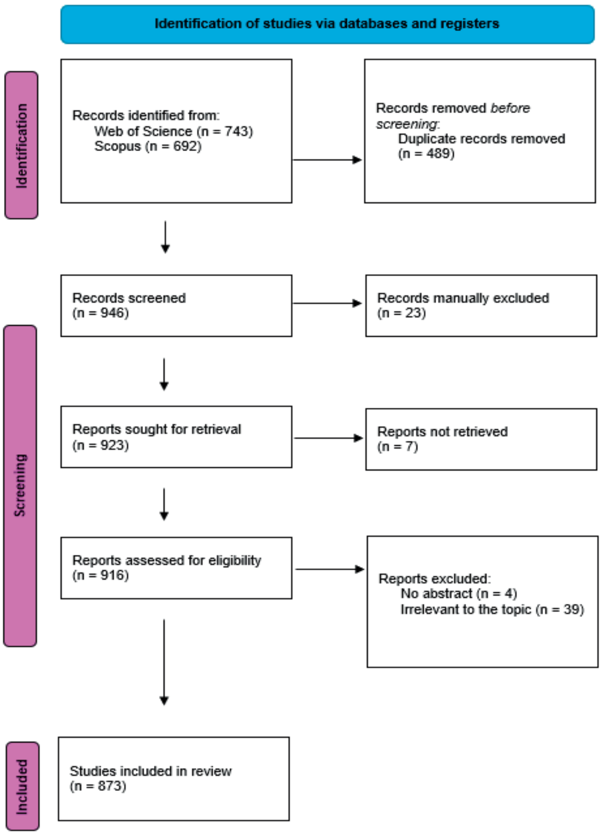

Figure 1. Selection process of the eligible reports based on the PRISMA 2020 flow diagram

The overall methodology is illustrated in Figure 2.

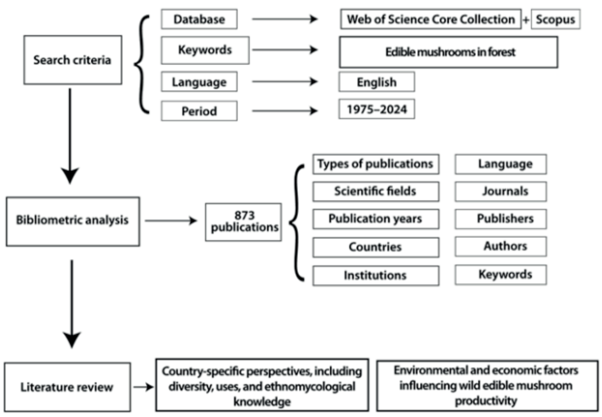

Figure 2. Schematic presentation of the workflow used in our research

RESULTS AND DISCUSSIONS

As of the year 2025, a total of 873 scientific publications have been identified in the field. Of these, the vast majority - 777 publications (approximately 89%) - were research articles, reflecting the predominant format for disseminating original scientific findings. Additionally, there were 44 review articles (5%), which synthesize existing knowledge and highlight research trends, as well as 35 proceedings papers (4%), typically derived from conference presentations and often representing emerging or preliminary research. Finally, 17 book chapters (2%) have been published, contributing to broader thematic volumes and offering in-depth discussions on specific subtopics within the field.

The published articles span across 57 distinct scientific fields. Among these fields, the highest number of articles were published in Environmental Sciences & Ecology, Forestry, Mycology and Plant sciences, respectively.

Many researchers have made significant contributions to this field. Jerzy Falandysz with 32 publications, followed by Ivan Siric (6 articles), Polashree Khaund (5), Miroslaw Mleczek (4), Jesus Perez-Moreno (4), and David Pilz (4) were among the most prolific authors.

The institutions most frequently associated with these authors include Fahrenheit Universities, University of Gdansk (65 articles), Universidad de Valladolid (28 articles), Universidad Nacional Autónoma de México (23 articles), Chinese Academy of Sciences (19 articles), Colegio de Postgraduados-Mexico (14 articles), Shinshu University, Japan (13 articles), Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) (10 articles), and Instituto de Ecología, Mexico (10 articles), respectively.

Researchers from 104 countries on five continents have contributed to articles on this topic. The most represented countries were Poland (123 articles), Mexico (88 articles), China (84 articles) and Spain (76 articles), respectively.

Countries were grouped into several clusters, with three main clusters each comprising six or seven countries: Cluster 1 includes the Czech Republic, Finland, Greece, Portugal, Serbia, Slovakia, and Turkey; Cluster 2 consists of Canada, Croatia, Italy, Pakistan, Saudi Arabia, and Tunisia; Cluster 3 comprises England, India, Malaysia, Philippines, South Korea, and the United States of America, respectively (Figure 3).

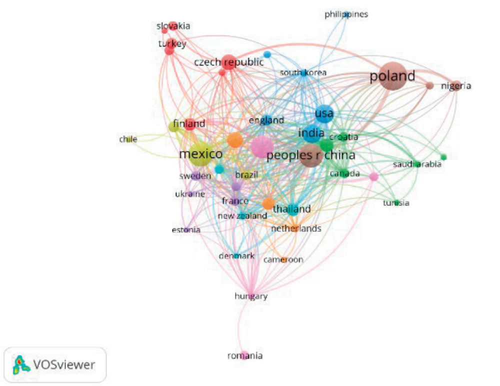

Figure 3. Clusters of countries with authors of articles on edible mushrooms in forest

Due to the large volume of articles published on this topic, a total of 3,441 keywords were identified, resulting in numerous keyword clusters. Among these, two clusters were particularly prominent because of their high number of keywords: Cluster 1 encompassed terms such as antioxidant activity, biodiversity, conservation, cultivation, diversity, edible mushrooms, forest management, fungi, growth, identification, macrofungi, management, mushrooms, species richness, and wild edible mushrooms, while Cluster 2 included keywords related to bioaccumulation, cadmium, food, fruiting bodies, heavy metals, mercury, and trace elements, respectively (Figure 4).

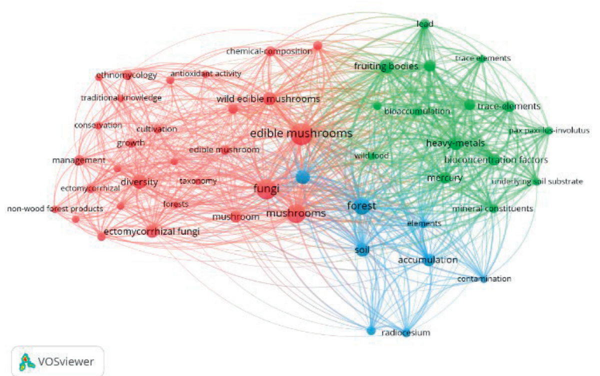

Figure 4. Authors' keywords concerning the edible mushrooms in forest

Country-level perspectives on edible mushrooms: diversity and utilization

In Italy, in the National Park Appennino Lucano, Val D'Agri, Lagonegrese (southern Italy), a list of 249 mushroom taxa exists. *Agaricus*, *Amanita*, *Boletus*, *Clitocybe*, *Hygrophorus*, *Lactarius*, *Mycena, Russula*, *Tricholoma*, and *Tuber* are the most representative genera. The rare *Amaurodon mustialaënsis* was also recorded, uniquely on white fir. 116 edible mushroom species were analyzed based on abundance and edibility (Venturella et al., 2016).

Slavonia Region from Croatia, country's key agricultural region, shows frequent use of edible fungi such as *Boletus* sp., *Cantharellus cibarius*, and *Lactarius piperatus*. *Auricularia auricula-judae* stands out as the only species reportedly consumed raw. Traditional use of *Sarcoscypha coccinea* adds valuable historical insight (Vitasović-Kosić et al., 2024).

In Romania, even if in recent years a decreasing interested in harvesting mushrooms was observed (Cioacă & Enescu, 2008; Scarlat & Enescu, 2025), mushrooms represent one of the most important categories of non-wood forest products (Enescu, 2017; Vasile et al., 2017; Enescu et al., 2018). At national level, toponymy reflects the cultural value of mushrooms: 13 cities, 3 rivers, 3 protected areas, and 1 landform are named after mushroom-related terms (Dincă et al., 2016). Particularly, In Horezu, mushroom picking is a significant local activity, with many residents engaged in selling raw or processed products, especially during tourist events (Enescu, 2022). Simultaneous activities such as truffle picking and hunting in forested areas pose significant safety hazards (Enescu & Drăgoi, 2019). National data on the quantities harvested remain limited, with only a few documented examples. A recent study involving 18 private companies from western Romania found that just 17% of wild edible mushrooms - primarily porcini and honey fungus - are consumed within the country. The majority are exported, mainly to Italy (37%), Spain (18%), Germany (13%), Austria (8%), and other countries (7%), including Japan and Canada (Budău, 2022). The medicinal role of edible mushroom is subject of traditional and modern medicine (Hălălișan et al., 2018; Dinulică et al., 2020).

Although Romania's natural forests and grasslands ecosystems remain largely intact and support exceptionally high mushroom biodiversity, with over 2,500 known species, including mycorrhizal, saprophytic, and parasitic types (Bontea, 1985), around 500 of which are considered edible (Sălăgeanu & Sălăgeanu, 1985; Tănase et al., 2009). The list of species authorized for commercialization is surprisingly limited to just 35. In contrast, other European countries, including those with similar ecological conditions in the Balkans and Carpathians, tend to have much more permissive regulations.

China hosts an exceptional diversity of 532 edible ectomycorrhizal (ECM) mushroom taxa across 62 genera and 28 families, including 39 ascomycetes and 493 basidiomycetes. Species richness peaks in *Russulaceae* and *Boletaceae*, with notable genera being *Russula*, *Lactarius*, *Ramaria*, *Hygrophorus*, *Suillus*, *Tricholoma*, *Tuber*, *Boletus*, *Amanita*, and *Cortinarius* (Wei et al., 2021). Some ECM mushrooms are economically significant, with global markets valued in billions (Wang & Hall, 2004). Traded sporocarps can exceed the value of local fruits and vegetables (Dell, 2002), and they are vital dietary sources rich in protein, fiber, and essential vitamins. In upland Southeast Asia, including Yunnan, Thailand, and the Philippines, ECM mushrooms are widely harvested and traded (Dell et al., 2000).

A highly mycophilic nation, Japan has advanced cultivation of culturally significant fungi, such as *Lyophyllum shimeji*, *Tricholoma matsutake*, and *Rhizopogon roseolus*. Other cultivated genera include *Astraeus*, *Cantharellus*, *Sarcodon*, *Suillus*, and *Tuber*. Innovations include the cultivation of *L. shimeji* without host plants. The decline of *T. matsutake* in *Pinus densiflora* forests has prompted major restoration and research efforts (Yamada et al., 2017).

In India (Northeast and Western Ghats), in Assam's Chirang district, 14 species of macrofungi from 12 genera and 10 families were recorded, mostly within *Agaricales* (64.3%). *Termitomyces* was the most frequent genus, with four new species recorded in the region. In the Western Ghats, ethnomycological knowledge encompasses 51 species across 23 genera. Hygroscopic earthstar [*Astraeus hygrometricus* (Pers.) Morgan], beefsteak fungus [*Fistulina hepatica* (Schaeff.) With.], and funnel cap [*Clitocybe infundibuliformis* (Pers.) Harmaja] are among the preferred edible mushrooms (Karun et al., 2017).

In Indonesia, in Kalimantan area, 20 wild edible mushroom species were identified, including *Auricularia*, *Campanella*, *Calostoma*, *Cookeina*, *Favolaschia*, *Inocybe*, *Termitomyces*, *Lentinus*, *Phallus*, *Pleurotus*, *Schizophyllum*, and *Volvariella* (Nion et al., 2024). In Pinrang Regency, five species were commonly used for food and medicine, while 13 species were non-edible or poisonous (Daud & Asis, 2021).

In Nepal, 228 mushroom species are consumed, mainly by high-altitude Tibeto-Nepalese communities. For these groups, mushroom foraging is a key subsistence practice, with households collecting as much as 160 kilograms annually. While wealth status doesn't affect collection rates, commercial collection is a significant income source for lower-income groups (Christensen et al., 2008).

In Ifugao Province from Philippines, 16 macrofungal species are used as food, including *Agaricus*, *Auricularia*, *Coprinus*, *Lentinus*, *Mycena*, *Oudemansiella*, *Phellinus*, *Pleurotus*, *Schizophyllum*, *Trametes*, and *Termitomyces* (De Leon et al., 2019).

In Tunisia's Kroumiria region, 482 mushroom species have been documented, with the orders *Agaricales* and *Pezizales* being the most dominant. The family *Tricholomataceae* showed the highest diversity. Genera such as *Russula*, *Amanita*, and *Boletus* were especially rich, with 337 species newly cited to the Tunisian fungal flora (El Monki et al., 2019).

Despite broad ethnomycological familiarity, particularly with *Amanita* species, in Burkina Faso knowledge and fungal diversity are declining due to environmental degradation and cultural loss (Dabiré et al., 2024).

In Burundi and Rwanda 77 edible species were recorded from diverse ecosystems. Among these, 39 were new to regional diets, and eight were previously not known to be edible (Degreef et al., 2016).

The Atewa and Bia forest reserves from Ghana exhibit significant wild mushroom diversity, though under threat from illegal mining. Collected species include representatives of *Cookeina*, *Marasmiellus*, *Auricularia*, *Daldinia*, *Pleurotus*, and *Polypores* (Dzomeku et al., 2023).

In Democratic Republic of Congo, in Yangambi and Yoko forest reserves support a rich fungal diversity, though local preference remains biased toward saprotrophic fungi in degraded forests, despite a high availability of ECM fungi (Milenge Kamalebo & De Kesel, 2020).

Among the Bakweri people from Cameroon, at least 15 edible species are known. Mushrooms are valued for food, medicine, and cultural purposes. The commonly genera include *Termitomyces*, *Auricularia*, *Agaricus*, *Pleurotus*, *Russula*, and *Ganoderma* (Kinge et al., 2011).

Wild edible mushrooms serve as non-wood forest products, providing food and income in Angola. Nutritional analyses revealed high carbohydrate and protein contents, and low-fat levels, with mannitol as the dominant free sugar (Kissanga et al., 2022).

In two districts from Tanzania, 98% of respondents collect mushrooms. Among the 28 identified edible species, local preferences are centered on *Amanita loosii*, *Cantharellus isabellinus*, *Clavulina wisoli*, *Lactarius edulis*, and *Termitomyces microcarpus* (Nyamoga, 2023).

Forest types significantly influence edible ECM taxa abundance, with the genera *Lactarius*, *Russula*, and *Amanita* being dominant in Benin. Seasonal and host tree variation affects productivity (Yorou et al., 2001).

In Mexico, edible fungi are integrated into biocultural traditions but increasing demand and unsustainable harvesting threaten their future. Research and domestication are needed to conserve this resource (Alvarado-Castillo et al., 2015).

Brazil is home to 409 edible mushroom species, of which 350 are considered safe for consumption. However, only 86 of these have been verified through molecular or taxonomic evidence, highlighting the need for further research (Drewinski et al., 2024).

In Argentina, seventeen species are used by Mapuche communities, with *Morchella* spp. having the highest cultural value, followed by *Suillus luteus* and *Cyttaria hariotti* (Molares et al., 2020).

In the Guatemalan Highlands, mushroom commerce is culturally rooted among Mayan communities. Market species include *Amanita*, *Cantharellus*, *Boletus*, *Lactarius*, and *Russula* (Mérida Ponce et al., 2019).

Among two peri-urban Kichwa communities from Ecuador, 50 wild edible species were recorded. *Favolus tenuiculus*, *Bresadolia paradoxa*, and *Lentinus concavus* were most culturally valued (Vicente-Pérez et al., 2024).

The global overview presented in this review reveals a remarkable diversity of wild edible mushrooms (WEM) and highlights the complex relationships between fungal biodiversity, cultural knowledge, and ecosystem dynamics across continents. From well-documented, commercially important species in East Asia to underexplored fungi in African and Latin American forests, the country-level data illustrates the breadth and depth of human-fungi interaction and the urgent need to document, conserve, and sustainably manage these resources.

The richness of edible mushroom taxa varies substantially across countries, reflecting local ecological conditions, forest composition, and research intensity. For instance, China stands out with 532 recorded edible ectomycorrhizal (ECM) taxa, highlighting the country's high fungal biodiversity and strong tradition of fungal utilization (Wei et al., 2021). Similarly, Brazil reports 409 edible species, although many remain poorly characterized and require further taxonomic study (Drewinski et al., 2024).

In contrast, in regions such as Burundi and Rwanda, Benin, and Tunisia, research has only recently begun to reveal extensive and often novel fungal diversity, including many species not previously known to be edible (Yorou et al., 2001; Degreef et al., 2016). The high proportion of ECM species, especially in woodland savannas and oak forests, suggests a strong ecological dependence on specific host tree associations, which must be considered in conservation planning.

Across continents, the traditional knowledge of WEM is deeply embedded in local cultures, particularly among indigenous and rural communities. For example, in India, the Bodo tribes and communities of the Western Ghats demonstrate detailed knowledge of seasonal availability, habitat, and culinary preferences (Devi et al., 2016; Karun & Sridhar, 2017). Similarly, in Argentina and the Philippines, species like *Morchella tridentina* and *Termitomyces* spp. hold high cultural and dietary value (Molares et al., 2020).

In Nepal, subsistence mushroom collection by high-mountain ethnic groups contributes significantly to household food supply and income, regardless of socioeconomic status (Christensen et al., 2008). This suggests that wild mushroom foraging serves not only ecological and nutritional roles but also functions as an egalitarian subsistence strategy in resource-limited settings.

Notably, in Cameroon and Guatemala, fungi are culturally used beyond nutrition - as medicine, spiritual symbols, and even in aesthetics and mythology - demonstrating the diverse ethnomycological landscape across regions (Kinge et al., 2011; Mérida Ponce et al., 2019).

In many regions, wild edible mushrooms represent both a critical food resource and an economic asset. In China, ECM sporocarps such as *Tricholoma matsutake* and *Tuber* spp. are luxury goods traded globally, fetching prices many times higher than seasonal vegetables and fruits (Dell, 2002; Wang & Hall, 2004). Similarly, Japan has made significant progress in cultivating culturally valued species such as *Lyophyllum shimeji* and *Rhizopogon roseolus* (Yamada et al., 2017).

Elsewhere, such as in Mexico and Indonesia, the pressure from commercial demand and lack of cultivation techniques threaten wild populations and the sustainability of traditional harvesting systems (Alvarado-Castillo et al., 2015; Nion et al., 2024). Despite the potential for economic upliftment, overharvesting and habitat destruction - such as illegal mining in Ghana - pose serious risks to fungal diversity and long-term community benefit (Dzomeku et al., 2023).

Several countries report that knowledge about edible fungi is disappearing, particularly in Burkina Faso, where environmental degradation and generational loss of ethnomycological knowledge coincide (Dabiré et al., 2024). Similarly, in Benin, fungal yields are closely tied to forest composition, yet pressure from deforestation threatens both the species and the traditional ecological understanding associated with them (Yorou et al., 2001).

There is a clear gap in fungal biodiversity documentation in tropical countries compared to temperate ones. While Italy's Appennino Lucano National Park has an unpublished list of 249 taxa, including rare and newly reported species, this reflects a more complete inventorying tradition compared to underexplored biodiversity hotspots like the Guatemalan Highlands or Ecuador, where community knowledge often outpaces scientific documentation (Venturella et al., 2016; Mérida Ponce et al., 2019; Vicente-Pérez et al., 2024).

Environmental and economic drivers of wild edible mushroom productivity

Using various species as case studies, we synthesize empirical findings from diverse ecological contexts worldwide.

One of the most well-studied commercial species is *Lactarius deliciosus*.

The work of Alfranca et al. (2015) highlights that meteorological and economic variables significantly influence the supply of this mushroom. Specifically, precipitation shows a negative impact on price changes (−0.104, t-value: −1.66), while temperature has a positive effect on harvest yields (0.605, t-value: 3.07). Including climatic variables enhances the explanatory power of economic models, often altering the interpretation of results significantly.

For black truffles (*Tuber melanosporum*) in Teruel, Spain, Ponce et al. (2010) employed a model based on ecological field theory to predict suitable climatic zones. This model offers a valuable tool for strategic cultivation planning in the region.

In tropical Africa, Badou et al. (2022) examined the influence of microclimatic conditions on *Boletus* species in Benin. Their findings reveal peak production in July and lowest yields in October. Interestingly, only soil moisture was found to have a statistically significant ($p > 0.05$) negative effect on abundance, indicating that microclimatic variability and vegetation type are key determinants of fruiting cycles.

Choi et al. (2024) investigated the effect of climatic variables on *Tricholoma matsutake* harvests in Yangyang-gun, Korea, employing augmented Dickey–Fuller and OLS tests. Results showed that an increase in average

August temperature correlates positively with *T. matsutake* harvests, with yields increasing by 1.5 tons per 1°C increase, suggesting a strong positive temperature-yield relationship.

In the Qilian Mountains, China, Huang et al. (2024) reported that the growth of *Lyophyllum decastes* and *Coprinus comatus* is primarily influenced by near-surface and air relative humidity, rainfall, and temperatures - indicating that hydrometeorological conditions are key factors in their development.

Similarly, Taye et al. (2016) identified late summer and early autumn precipitation as the primary climatic drivers for sporocarp emergence and productivity in *Pinus pinaster* forests of Central Spain. Soil acidity promoted *Lactarius* yield, while older stands and sandy soils were associated with decreased productivity.

Climate change impacts on forest fungi are evident in the work of Salerni et al. (2023), who studied *Boletus edulis* productivity in *Abies alba* plantations. They found that sudden spikes in maximum temperature inhibited productivity in unthinned areas, whereas heavily thinned areas showed a positive yield response - beginning approximately 20 days after extreme temperature events - suggesting that forest management practices can buffer climate extremes.

Regeneration cuttings (especially clear felling), catastrophic wind-falls or mass-dieback caused by drought, floodings, defoliators or lethal pathogens create favorable conditions for the development of record productions of xylophagous mushrooms (species of *Armillaria, Fistulina, Ganoderma, Hericium, Panus, Pleurotus, Polyporus*, etc.), but stopped the development of ectomycorrhizal species (Chira & Chira, 2001; Mihalciuc et al., 2003; Fernández- Fernández et al., 2019; Borgmann-Winter et al., 2022).

The ecological niche of *T. matsutake* in Xiangcheng County, China, has also been characterized in detail by Wang et al. (2020). Optimal conditions include altitudes of 3000-3900 m, average temperatures between 10.0-14.5°C, and 500-800 mm precipitation between April and October. The species prefers well-vegetated alpine oak and pine forests with slopes between 25°-35°, thriving especially under sunny days and rainy nights from late July to mid-September.

At the landscape scale, Ambrosio et al. (2024) explored *Boletus edulis* distribution using species distribution modeling. Contrary to earlier studies, they found that local edaphic conditions and geochemical soil content were more predictive of macrofungal assemblages than vegetation or climate, although at broader spatial scales, both climatic and soil variables were critical. Precipitation during the driest month emerged as the most significant climatic determinant.

Kewessa et al. (2022) demonstrated that in Ethiopian forests, sporocarp production and fungal richness were closely tied to soil organic matter, phosphorus, nitrogen, and minimum daily temperature. The study advocates for ecosystem integrity as a dual strategy for biodiversity conservation and economic enhancement through non-wood forest products.

Parad et al. (2020) analyzed the occurrence of *Cantharellus alborufescens* in Iran's oak-hornbeam stands. Key determinants included soil C content, C: N ratio, texture (sand and clay percentages), and water content. Comparative analysis with non-*Cantharellus* plots confirmed that these edaphic factors were significantly higher in productive sites.

Salo and Kouki (2018) examined the effects of wildfire severity on ectomycorrhizal (ECM) fungal communities. Their long-term study showed that low-severity fires retained the highest ECM richness (87 species), while high-severity crown fires had severely diminished diversity (15 species). The results underline the critical influence of fire intensity on post-disturbance fungal assemblages and their subsequent impact on forest regeneration.

In summary, wild edible mushroom productivity is shaped by a complex interplay of climatic, edaphic, and ecological factors. Understanding these drivers across species and regions is essential for sustainable harvesting, cultivation planning, and forest ecosystem management under changing climate scenarios.

Climatic variables as primary drivers

Across all case studies, temperature and precipitation consistently emerge as key climatic determinants of mushroom productivity. For example, in the case of *Tricholoma matsutake* (Wang et al., 2020; Choi et al., 2024), *Lactarius deliciosus* (Alfranca et al., 2015) and *Tuber melanosporum* (Ponce et al., 2010) strong correlations with moisture availability and seasonal temperature patterns were highlighted. Particularly, in the case of matsutake (*Tricholoma matsutake*) the positive effects of increasing summer temperatures on harvest yields, suggest that some mushrooms may profit from mild temperatures increases. Nonetheless, this pattern is not consistently linear or positive. For example, in forests without active management, Salerni et al. (2023) indicated that severe temperature spikes may reduce fungal productivity. Moreover, it was demonstrated that the seasonal rainfall and relative humidity not only have a strong influence, but they can also impact the fruiting (Taye et al., 2016; Huang et al., 2024). According to these results, it can be stated that moderate climate changes may be favorable for some mushroom species, while the extreme events, which were reported to be more frequent in the last decades, have a significant impact on both fungal diversity and productivity.

Microclimatic and edaphic influences

According to recent studies (Vasile et al., 2017; Tudose et al., 2023), microclimatic and edaphic conditions have also a determinant role. Organic matter content, soil texture, and nitrogen and phosphorous availability influence the fungal community and the sporocarp production (Badou et al., 2022; Kewessa et al., 2022; Parad et al., 2020). If in the case of *Cantharellus alborufescens* the higher productivity is reached in clay-loam soils exhibiting specific C: N ratios (Parad et al., 2020), as regards *Boletus edulis*, its productivity is influenced by the soil geochemistry and texture at local scales than to macroclimatic conditions (Ambrosio et al., 2024). These findings highlight the importance of site-specific soil assessments in predicting mushroom yields and underline the limitations of broad-scale climate-based models.

Forest structure and management

Forest composition, age, and management also substantially influence mushroom productivity (Dincă et al., 2020; Murariu et al., 2021; Dincă et al., 2022). The role of thinning and forest canopy openness in modulating microclimatic conditions and supporting fungal growth is particularly evident in *Boletus edulis* habitats (Salerni et al., 2023). Likewise, the presence of specific forest types (e.g., mixed pine-oak or alpine oak forests) appears essential for the growth of *T. matsutake* in China (Wang et al., 2020).

These insights support the emerging field of mycosilviculture, which integrates fungal productivity into forest management planning. Sustainable forestry practices that maintain or enhance soil health, vegetation diversity (Budeanu et al., 2014; Şofletea et al., 2015; Apostol et al., 2020; Marcu et al., 2020; Besliu et al., 2024), and canopy structure could enhance mushroom yields while supporting broader biodiversity and ecosystem services. In mountain relatively humid *Pinus sylvestris* zone, the soil expectation value of mushroom yields was significantly higher than of timber production; but in more arid hilly *P. nigra*-dominates stands, the effect increased. Forest management may (positively and negatively) influence the mushroom productivity, according to the fungal type (saprotroph, ectomycorrhizal) and ecological requirement, stand type and forest regime (Tomao et al., 2017). Macromycetes diversity is positively related to stand age, density and structure, quantity of dead wood, and low management intensity (Tomao et al., 2020).

The production of edible mushrooms in forests, also known as mycosilviculture, is an area of growing interest, with trends indicating a shift towards both sustainable wild harvesting and controlled cultivation methods. This field aims to integrate the cultivation and management of edible ectomycorrhizal (ECM) fungi into forest ecosystems for economic and ecological benefits (Ruiz-Almenara et al., 2019; Rantanen, 2021). The impact of intensive mushroom harvesting on forest stability has not been proven, but the subject remains controversial (Ruiz-Almenara et al., 2019).

Economic and market considerations

Economic drivers, though less frequently quantified, are no less important. Market dynamics, such as price fluctuations due to supply variability, feed back into harvesting pressure and land-use decisions (Jacob et al.,

2025). Precipitation on mushroom yield and price, indicating a supply-driven market volatility that can influence harvesting behaviors and resource sustainability (Alfranca et al., 2015).
Additionally, increasing commercial interest in high-value species like truffles and *T. matsutake* has spurred cultivation efforts in climatically suitable areas (Ponce et al., 2010), linking ecological modeling with economic planning. However, this also raises concerns about overexploitation, land conversion, and social equity in access to forest products.

Towards integrated models of mushroom productivity

Overall, the literature indicates that no single variable can fully predict wild mushroom productivity. Rather, it is the interaction among climatic, edaphic, biotic, and anthropogenic factors that shape the outcomes. Integrated models that account for this complexity - combining ecological, meteorological, and economic data - are needed for more accurate forecasting and sustainable management (Davidescu et al., 2012; Mihalache et al., 2020; Marin et al., 2024).
Moreover, these findings have broader implications for food security, forest-based livelihoods, and conservation planning. Protecting the ecological conditions that support wild edible mushrooms is not just about preserving gourmet delicacies - it is about safeguarding culturally significant, nutritionally valuable, and ecologically critical components of forest ecosystems.

CONCLUSIONS

This review of edible mushrooms from the forests revealed a growing global interest in their multiple uses worldwide. The study highlighted key thematic trends, influential publications, and patterns of international collaboration, indicating a multidisciplinary and international focus on this subject. These findings indicate that scholarly attention has primarily focused on the country-specific perspectives and the environmental and economic factors influencing their productivity. Edible mushrooms exhibit significant biochemical and nutritional diversity shaped by species-specific and ecological factors, highlighting their potential value as functional medicinal and food compounds. Even if their nutritional and medicinal potential is well known and globally appreciated, several challenges in terms of cultivation and harvesting still exist.
The country-level variability of the edible mushrooms and their diverse ethnomycological knowledge highlight the necessity of sustainable use and regional conservation strategies, which must play a crucial role both in food security and forest management globally.
At a local scale, since the productivity of wild edible mushrooms depends on a broad edaphic, climatic, economic and ecological factors, site-specific management practices are needed.

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