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Ecological Roles and Cultivation Status of Wild Mushrooms with Economic and Biotechnological Importance

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ABSTRACT

Rising global demand for natural resources and the pursuit of sustainable production have amplified interest in the cultivation of valuable wild mushrooms. Concerns over overharvesting pressures on natural populations and the preservation of biodiversity have made the controlled cultivation of these species both a scientific and economic necessity. Concordantly, wild mushrooms are re-evaluated not only for their role in the food industry but also as strategic resources with medical, functional, and biotechnological applications.

This study examines the cultivation status of economically important species, focusing on their ecological roles, domestication challenges, and potential uses. Fungi classified as saprotrophic, mycorrhizal, or parasitic exhibit diverse ecological functions. Saprotrophic species such as shiitake and oyster mushrooms have been the most successfully cultivated due to their environmental adaptability. In contrast, mycorrhizal species such as truffles and porcino require complex agroforestry systems due to their symbiotic relationships with host plants.

The importance of understanding fungal ecology, substrate requirements, and environmental parameters is emphasized for successful cultivation. It also evaluates the medicinal and functional properties of mushrooms, such as antitumor, antioxidant, and immunomodulatory effects, underscoring their pharmacological value. Mycelium-based biomaterials and environmental remediation are also addressed as emerging biotechnological applications. Despite recent progress, many species remain uncultivated due to ecological and technical complexities. This review examines global cultivation challenges through the lens of Türkiye, a region with rich ethnomycological value and potential. Thereby, it highlights the need for interdisciplinary approaches to advance cultivation, conserve biodiversity, and realize the economic and scientific potential of wild mushrooms.

Keywords: Wild mushrooms, cultivation, mycorrhizal fungi, saprotrophic fungi, medicinal mushrooms, biotechnology.

1. Introduction

Fungi are eukaryotic organisms that originated from the same heterotrophic common ancestor as animals and have cell walls composed of chitin (Richards et al., 2017). Whittaker (1969) distinguished three major life forms for macroorganisms: (1) photosynthetic, usually immobile autotrophs (phytoids), (2) frequently immobile heterotrophs with cell walls (fungoids), and (3) wallless phagotrophs (zooids) (Cavalier-Smith, 2001). Fungi, which are classified in a kingdom of their own according to this definition, offer the primary decomposer role ecologically and/or establish symbiotic relationships (Richards et al., 2017). With these traits, mushrooms have ecological importance with a key role in the ecosystem, and due to their great diversity (Senn-Irlet et al., 2007; Zotti et al., 2013). Fungi exist in nature in three morphs; (1) the unicellular morph that reproduces by budding in liquid or moist environments is called yeast, (2) the hyphal morph that does not show differentiation at the organ level is called mold, and (3) the multicellular morph that differentiates at the tissue and organ level and forms a visible sporocarp is called mushroom or macrofungus (Burge & Otten, 1990; Cooke, 1871).

Macrofungi consist of two parts: thallus and mycelium. Thallus (also known as carpophore, mycocarp, sporocarp, or fruiting body), which is formed by the differentiation of hyphae, is the consumed part and consists of parts called the stem, cap, and sporophore. Mycelium is the name given to the entire hyphal network that remains under the surface and surrounds the soil, roots, or food (Figure 1) (Kalac, 2001). Mycelium is the vegetative structure that the fungus inhabits during its primary life stage which is also the part that performs its crucial ecological functions, such as decomposing organic matter beneath the soil and/or facilitating symbiotic relationships with plants often referred to as the "wood wide web" (Kalac, 2001; Simard & Durall, 2004; Van Der Heijden & Hortan, 2009). Although this part can survive for long periods and continue to live vegetatively, the loss of precursor cells over time or due to environmental conditions and the atrophy of the ability to divide and grow through senescence (aging) threatens the survival of the fungus if its mycocarps cannot fulfill their functions (Griffiths, 1992; Keyes et al., 2021). This shows that, in addition to preventing habitat loss for the protection of mushroom species, it is also necessary to prevent excessive consumption of fruiting bodies and that cultivation may be an effective measure in this regard (Senn-Irlet et al., 2007; Zotti et al., 2013).

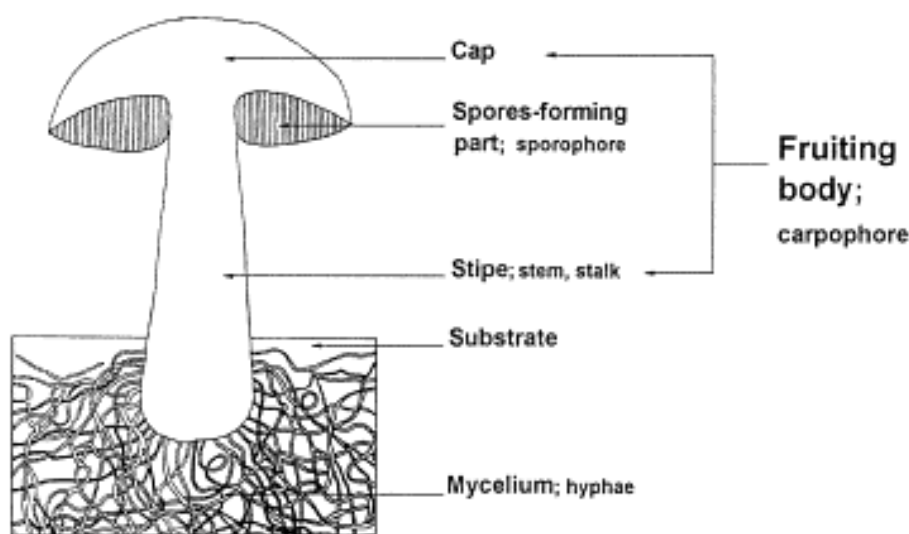


Figure 1 A visual of the above and below-ground parts of the mushroom and mycological terms for the parts of a cap mushroom (Kalac, 2001).

1.1. Fundamentals and Development of Mushroom Cultivation

1.1.1. Fundamental Difficulties Encountered in the Cultivation Process

Cultivation of wild mushrooms presents significant challenges due to the complexity of their natural life cycle. Symbiotic relationships established with plant roots, especially in mycorrhizal species such as truffle and porcino, are difficult to recreate in the laboratory environment, and this process often takes many years (Huang et al., 2024; Reyna & Garcia-Barreda, 2014). Saprophytic species (e.g., shiitake and oyster mushrooms) require specific substrate and microclimate conditions (S. T. Chang & Miles, 1987). These conditions include physiological factors such as temperature, light, humidity, ventilation, and gravity. In addition, the production process may need to be provided with appropriate proportions and combinations of essential nutrients such as carbon, nitrogen, minerals, and vitamins, further complicating the production process (S.-T. Chang & Miles, 2004; Reyna & Garcia-Barreda, 2014).

Another fundamental problem encountered in the cultivation of wild mushrooms is the risk of contamination and disease agents. Viral, bacterial, or fungal infections, as well as nematode and insect pests, can seriously threaten production. Therefore, hygienic and sterile conditions must be constantly provided. The fact that such infectious or environmental stresses cause some mushrooms to produce mycotoxins is one of the inconveniences of wild mushroom consumption and one of the difficulties in cultivation (S.-T. Chang & Miles, 2004; Schmidt-Heydt et al., 2008). On the other hand, the fact that mushrooms grown in culture do not have the same aromatic qualities as samples collected from nature can lead to some limitations, especially in the field of gastronomy. In addition to these physiological, environmental, and biological difficulties, the high initial costs encountered in the production of wild mushrooms also constitute an economic obstacle. However, biotechnological advances and ecosystem-based production approaches in recent years have enabled the development of more efficient and sustainable methods in wild mushroom cultivation (S.-T. Chang & Miles, 2004; Regis & Geösel, 2023).

1.1.2. History of Cultivation and Cultivation Methods

The first example of mushroom cultivation was the cultivation of the species *Auricularia auricula-judae* (wood ear mushroom) between 600 and 300 BC. In this example, the species was not isolated, but only the logs on which the mushroom grew were collected and fed with other logs suitable for the mushroom; it is the most primitive form of outdoor mushroom cultivation known (Regis & Geösel, 2023). Following the wood ear mushroom, *Flammulina velutipes* (enoki) was cultivated by the same method around 800 AD, and *Lentinula edodes* (shiitake) around 1000 AD (S. T. Chang & Miles, 1987; S.-T. Chang & Miles, 2004). For the first time, the *Lentinula edodes* inoculation method was used in the 13th century, thus becoming the modern form of outdoor cultivation (Sau-Wa Mak, 2024). This method is currently carried out by inoculating sterilized logs with nutrients enveloped by mycelia that are either known to be sterile or have been sterilized (Figure 2).

The cultivation of *Agaricus bisporus* (white button mushroom), which is widely produced and consumed today, is the oldest and most primitive example of isolated cultivation using isolated environments such as caves (S. T. Chang et al., 1985). In this example, caves served as today's climate-controlled chambers, controlling light, temperature, and humidity. The first isolation of cultures and modern cultivation were achieved in the 19th century through the development of pressurized sterilization techniques and climate-controlled growth chambers (S.-T. Chang & Miles, 2004; Ferenczy, 1981). Today, sterilization and culture isolation stages are encountered in all mushroom production.



Figure 2 Cultivated *Lentinula edodes* (Shiitake) on a log, an example for outdoor cultivation methods (Organic Shiitake Mushroom Plug Spawn, n.d.).

While these two methods are used for the culture of saprotrophic fungi, the third cultivation method, agroforestry integration, is the most effective method for the culture of mycorrhizal fungi (Reyna & Garcia-Barreda, 2014). Agroforestry integration is a cultivation method that involves inoculating the roots of plants with the mycelia of fungi compatible with the species in a sterile environment (Kalenius, 2022). The earliest applications of this method originated in Italy, where oak seedlings were cultivated from acorns collected beneath truffle-producing trees. However, the success of this approach was limited to local conditions (Zambonelli et al., 2015). With the understanding of truffle mycelial structures in the 1970s, three of the most promising methods were tested: (1) the mother plant method, which involves the colonization of seedling roots by mycelium from the base of the parent plant; (2) the mycelial inoculation method; and (3) the spore inoculation method (Chevalier, 1973; Zambonelli et al., 2015). Although the mycelial inoculation method showed considerable promise, the spore inoculation technique rapidly became the most widely adopted approach. In contrast to the other two methods, the agroforestry integration approach involves transplanting the symbiotic fungus along with the host plant into the field only after both have reached sufficient maturity (Kalenius, 2022).

In 1984, approximately 70% of global edible mushroom production consisted of *Agaricus bisporus* (button mushroom), followed by 14% *Lentinula* (shiitake), 4% *Volvariella volvacea* (straw mushroom), and 2.8% *Pleurotus* spp. (Oyster mushroom). By 2013, the distribution had shifted to 22% *Lentinula* (shiitake), 19% *Pleurotus* (oyster), 18% *Auricularia* (wood ear), 15% *Agaricus* (button mushroom), 11% *Flammulina* (enoki), 5% *Volvariella* (straw mushroom), and 10% other species (Figure 3) (Stabnikova et al., 2024). Although their production volumes remain relatively low, many mushroom species have been brought into cultivation for use in medicine, food, biotechnology, and scientific research. Examples of such species include *Cordyceps militaris*, *Hericium erinaceus*, *Grifola frondosa*, and *Phallus indusiatus* (S.-T. Chang & Miles, 2004; Krishna et al., 2025; Mayuzumi & Mizuno, 1997; Wong et al., 2009). The fact that *Pleurotus* and *Agaricus* species, together accounting for only 34% of global production, are the most commonly consumed mushrooms in Türkiye may indicate that mushroom production should be adapted to local ethnomycological preferences.

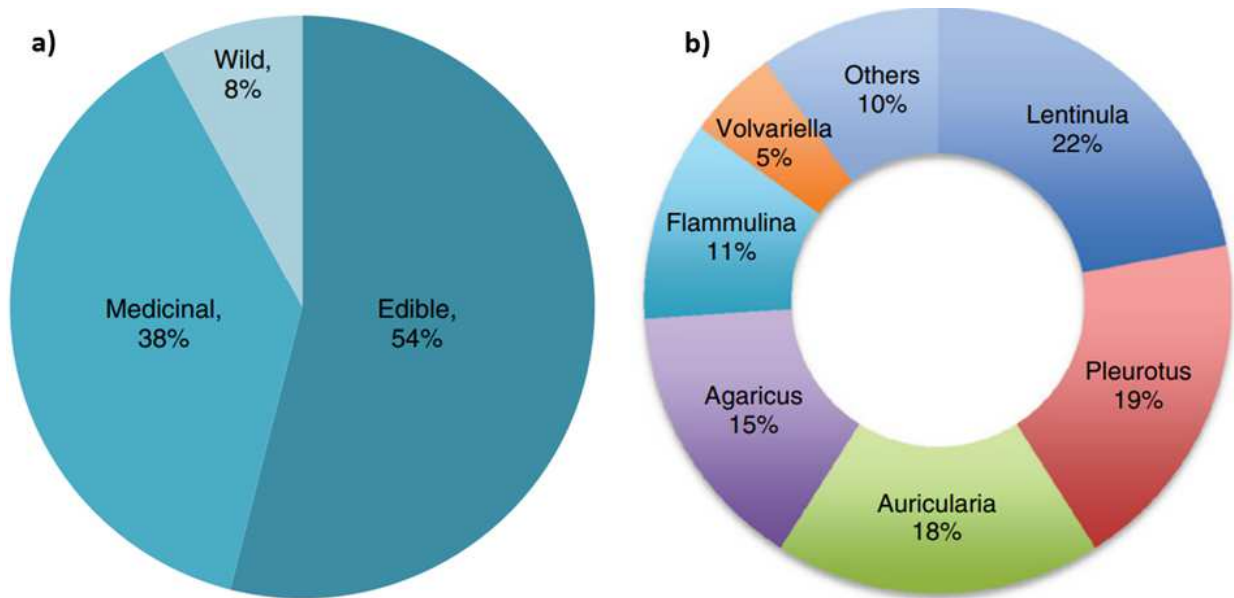


Figure 3 Pie charts showing: (a) global mushroom industry distribution, and (b) global edible mushroom production shares in 2013 (Royse et al., 2017; Stabnikova et al., 2024).

1.2. Focus of the Study and Its Objectives

Wild mushrooms are under threat due to overharvesting and habitat loss, despite their high economic value in gastronomy and medicine. The primary objective of this study is to evaluate the cultivability of economically valuable wild mushrooms by examining their scientific, methodological, and ecological aspects. The domestication process aims to simulate the ecological requirements of fungi in their natural habitats, including abiotic and biotic conditions, in artificial environments. Through the integration of these species into sustainable production systems, it seeks to prevent the degradation of natural populations caused by overharvesting (Zotti et al., 2013).

In this study, high-value macromycetes with both gastronomic and pharmacological relevance (e.g., *Morchella*, *Ganoderma*, *Cordyceps*, and *Tuber*) were focused on, with their cultivation protocols, mycelial development, mycorrhizal associations, production infrastructure, encountered technical challenges, and economic potential being evaluated. Additionally, the relationship between mushroom cultivation and ecosystem health, soil fertility, rural development, and biotechnological applications has been briefly addressed. Within this context, the compilation and evaluation of existing literature anticipate a systematic examination of research areas regarding the domestication of wild mushrooms. The assessments obtained aim to identify gaps in scientific knowledge within this field and establish focal points that could form a basis for future interdisciplinary studies. These evaluations seek to contribute to understanding the challenges in wild mushroom domestication and the agroforestry integration of mycorrhizal species.

2. The Mushroom Industry and Cultivation Status

Culture refers to the process of growing an organism by replicating its natural habitat conditions and ecological requirements within a controlled, confined, and specialized setting. Therefore, understanding fungal ecology is essential for both the domestication of species and ensuring productivity (Zotti et al., 2013). Fungi are fundamentally categorized into three main ecological roles: saprotrophic, mycorrhizal, and parasitic, based on their ecological niches (Stamets, 2004).

2.1. Cultivation Status of Saprotrophic Fungi

Although the term saprotrophic fungi encompasses certain internal distinctions, it fundamentally refers to all fungi that decompose degraded or decaying organic material without requiring a host organism (Woodward & Boddy, 2008). Due to their non-requirement of a host organism, they are typically cultivated using outdoor cultivation or climate-controlled chamber methods. The most commonly cultivated species, which constitute the majority of production volume, *Lentinula*, *Pleurotus*, *Auricularia*, *Agaricus*, *Flammulina*, and *Volvariella*, are all saprotrophic fungi. Among all ecological roles, saprotrophic fungi present the least challenges during production stages (S.-T. Chang & Miles, 2004; Stabnikova et al., 2024). However, the complexity of the required nutrients or other environmental ecological needs may still present certain challenges in cultivating saprotrophic fungi (Kuznetsov, 2010).

For instance, *Cordyceps militaris*, a saprotrophic–transitional (or predatory) fungus, has been successfully domesticated and cultivated on various nutrient media. In contrast, *Ophiocordyceps sinensis* has not yet been domesticated, as it specifically feeds on the larvae of certain host species such as *Thitarodes* spp., and cultivation strategies for its conservation are still under investigation (Krishna et al., 2025). Moreover, although *Phallus impudicus* is saprotrophic and not mycorrhizal-transitional, the application of an agroforestry integration method may still be required for mycocarp development, involving the transplantation of laboratory-grown mycelia beneath garden plant cover (Kuznetsov, 2010).

2.1.1. Cultivation Status of Saprotrophic Fungi Valuable to the Food Industry

The species *Lentinula edodes*, *Pleurotus ostreatus*, *Auricularia auricula-judae*, *Agaricus bisporus*, *Flammulina filiformis*, and *Volvariella volvacea* exhibit significant differences in cultivation conditions and substrate preferences. For instance, while *Lentinula* and *Auricularia* thrive on hardwood sawdust or logs, *Pleurotus* and *Volvariella* preferentially grow on agricultural wastes (straw, rice straw) (Figure 2 & 4). *A. bisporus*, the most widely cultivated species at an industrial scale, requires specialized compost and casing soil. Temperature requirements vary among species; *Volvariella* prefers tropical conditions (28-35°C), whereas *Flammulina* shows cold tolerance (8-12°C). Humidity levels (70-95%) and light requirements are also species-specific. These variations necessitate customized approaches in mushroom cultivation, from substrate selection to climate control. While *L. edodes*, *P. ostreatus*, *A. auricula-judae*, and *V. volvacea* are typically cultivated in open-field systems, *A. bisporus* and *F. filiformis* generally require fully controlled sterile climate chambers (S.-T. Chang & Miles, 2004).

Phallus indusiatus, also known as *Dictyophora indusiata*, is one of the saprotrophic species that can be successfully cultivated without major difficulties (S.-T. Chang & Miles, 2004). Although it does not have a large global production volume, it holds economic value in China due to its important ethnomycological role. The same applies to *Hypsizygos tessellatus* (shimeji) and *Grifola frondosa* (maitake) (S.-T. Chang & Miles, 2004; Kuznetsov, 2010; Woodward & Boddy, 2008). *Laetiporus sulphureus* is a cultivated species that has gained popularity in the Western world for its status as a gourmet mushroom (Çevrim, 2023; Yılmaz & Zencirci, 2015). This suggests that cultivation efforts can potentially target species with established cultural value; this approach could also be applied to many other locally important species, as seen in the Türkiye example.

In various countries on a global scale, several saprotrophic species that are also known to be culturally foraged, consumed, or used as food, such as *Macrolepiota procera*, *Agaricus campestris*, *Cyclocybe cylindracea*, *Lycoperdon perlatum*, and *Lepista nuda*, are already embedded in local culture and commonly foraged and consumed by rural communities in Türkiye (Çevrim, 2023; Yılmaz & Zencirci, 2015). These species, which have considerable potential as food sources, and their local importance offers a foundation for supporting future cultivation efforts, have not yet been successfully domesticated; although their hyphae can be propagated under *in vitro* conditions, the environmental parameters required for mycocarp formation remain undetermined (Díaz-Talamantes et al., 2017; Landingin et al., 2020; Pekşen & Kibar, 2017; Pinto et al., 2013; Zhang et al., 2025). In some species, the inability to produce mycocarp is thought to result from the absence of appropriate substrates or environmental conditions. In others, it is hypothesized that they may be mycorrhizal or exhibit characteristics similar to mycorrhizal fungi, potentially requiring signaling cues from surrounding plants. For instance, in species such as *Morchella angusticeps*, *M. elata*, and *M. esculenta*, which are considered to be mycorrhizal-transitional, mycelia can be propagated under *in vitro* conditions and subsequently cultivated through agro-integration methods. However, the critical factors governing this process have not been fully identified, and standardized production protocols have yet to be established (Huang et al., 2024; Kuznetsov, 2010; Woodward & Boddy, 2008).

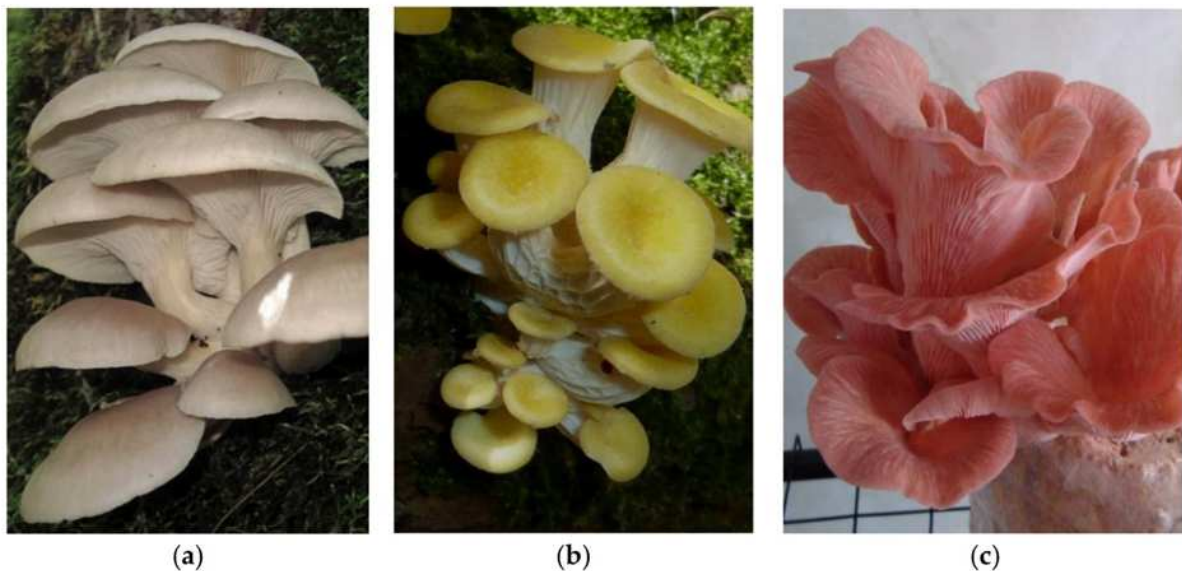


Figure 4 *Pleurotus* (oyster) mushrooms in different colors: a) *P. ostreatus* (grey oyster mushroom), b) *P. citrinopileatus* (golden oyster mushroom), c) *P. djamor* (pink oyster mushroom) (Tiupova et al., 2025).

2.1.2. Cultivation Status of Saprotrophic Fungi Valuable to the Pharmaceutical Industry

Species such as shiitake, oyster mushrooms, maitake, enoki, buna shimeji, and *Auricularia auricula-judae* stand out not only for their value in the food industry; but also for their functional properties and medicinal applications. Likewise, *Hericium erinaceus* (lion's mane), which is valued as a gourmet mushroom, and *Coprinus comatus* (shaggy mane), which also holds ethnomycological relevance in food use, are primarily recognized for their medicinal significance. Other saprotrophic species with exclusively functional uses and pharmacological importance include *Ganoderma lucidum* (reishi), *G. applanatum*, *Trametes versicolor* (turkey tail), *Schizophyllum commune*, and *Phallus impudicus* (S.-T. Chang & Miles, 2004).

Shiitake is noted for its immune-enhancing properties, oyster mushroom for its antioxidant and antimicrobial effects, and maitake for its antitumor activity (Kupcova et al., 2018; Patel et al., 2012). While Enoki mushroom displays anticancer properties, Buna shimeji mushroom is known for its hepatoprotective effects (Shah et al., 2018). Lion's mane mushroom is being investigated for its neuron growth factor-stimulating impact in neurodegenerative diseases such as Alzheimer's, while Shaggy mane is being investigated for its antidiabetic properties (Z. Gao et al., 2021; Thongbai et al., 2015). *Ganoderma* species (*G. lucidum* and *G. applanatum*) present anticancer, anti-inflammatory, and adaptogenic effects (Y. Gao et al., 2004; Jong & Birmingham, 1992). *Trametes versicolor* is important for chemotherapy support, and *Schizophyllum commune* is important for its antiviral and antitumor activities (Ajibola et al., 2024; Puia et al., 2018). *Phallus impudicus* has been used in traditional medicine to treat gout (Buko et al., 2019). Unlike the species *Phallus indusiatus*, *P. impudicus* has been cultivated, although not ethnomycologically, because of its immunomodulatory (immune system regulating) and effectiveness on wounds that are difficult to heal (Buko et al., 2019; Kuznetsov, 2010; Zakrzaska et al., 2024).

All of these species are saprotrophic and their cultivability levels have been proven to be successful to a large extent. Species such as shiitake, oyster, enoki, and buna shimeji are fully cultivated saprotrophic mushrooms that have been widely used in both industrial and small-scale production for a long time. *Ganoderma lucidum* (Reishi) has been successfully grown in both solid substrates and liquid fermentation systems (Zhou, 2017). Cultivation is also possible in lion's mane and maitake species, but the fructification of these species is generally slower and more sensitive to environmental conditions, and they are less efficient in terms of metabolites produced than wild samples (Wong et al., 2009). Although *G. applanatum* and *C. comatus* have been cultured at the mycelial level, triggering their fruiting in a controlled environment is quite difficult (Jang et al., 2009; Jo et al., 2009).

2.2. Cultivation Status of Mycorrhizal Fungi

Mycorrhiza is generally the name of the mutualistic relationship between the roots of higher plants and true fungi (Goltapeh et al., 2008). In this symbiotic partnership, the photosynthetic partner is termed the photobiont, while the fungal partner that envelops the soil and provides mineral/nutrient support to the photobiont is called the mycobiont (Figure 5)(Honegger, 1996). Since mycorrhizal fungi primarily obtain their nutrients from their photobiont hosts in symbiosis, they are unable to decompose organic material in the substrate unless they are saprotrophic-transitional species. Therefore, their cultivation requires the simultaneous growth of host plant species with which they can form associations. For this reason, to date, mycorrhizal fungi have only been successfully domesticated through agroforestry integration methods.

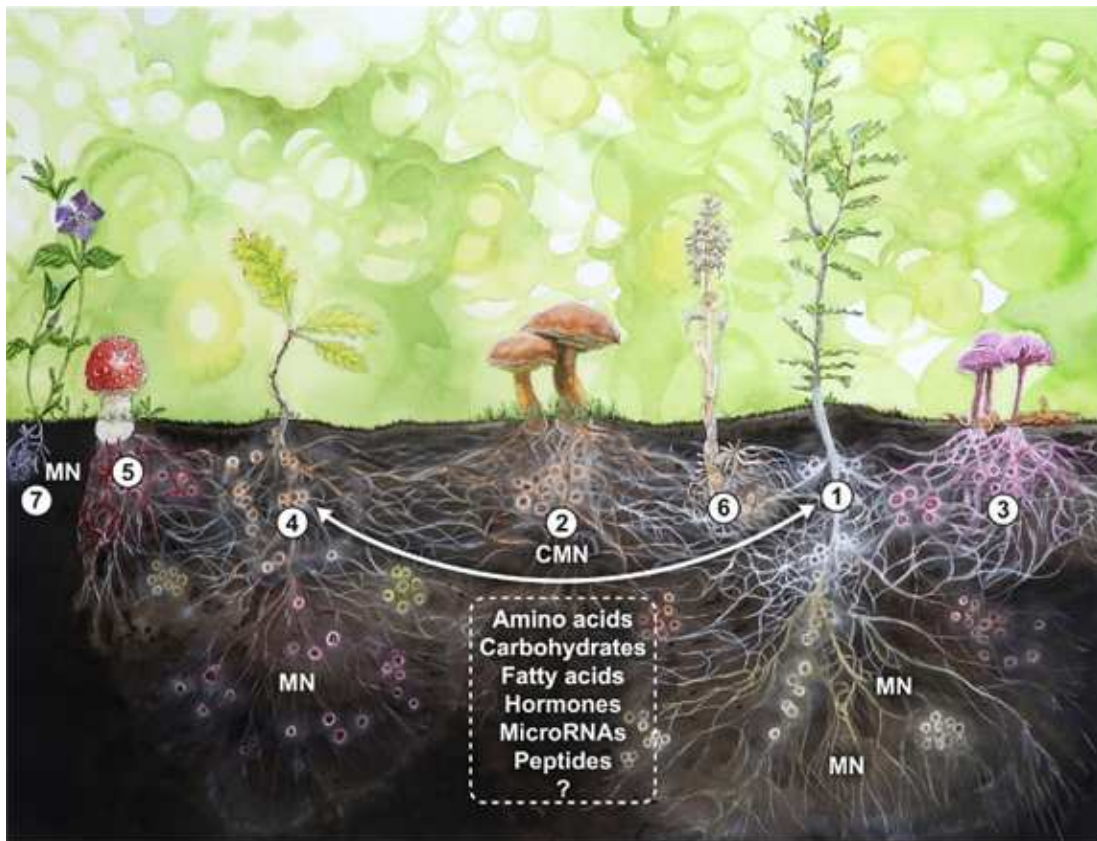


Figure 5 Representation of mycorrhizal networks (MN) formed by underground associations in a forest presumed to be dominated by oak species associated with different types of mycorrhizal fungi (Martin & van der Heijden, 2024).

2.2.1. Cultivation Status of Mycorrhizal Fungi Valuable to the Food Industry

Some of mycorrhizal mushroom species that have high value to the food industry have been successfully domesticated and are now produced on a commercial scale. This success has been achieved primarily by establishing symbiotic associations between the fungi and suitable host plants under laboratory conditions and maintaining these associations in controlled environments. One of the most well-known examples includes truffle species such as *Tuber melanosporum*, *Tuber magnatum*, and *Tuber aestivum*, which have been prioritized and cultivated due to their high economic value and unique aroma. In this method, seedlings of host plants (such as oak or hazelnut) are inoculated with truffle spores or mycelia and then planted in the field to facilitate symbiosis with the roots (Figure 7)(Coleman et al., 2025; Reyna & Garcia-Barreda, 2014; Zambonelli et al., 2015). Similarly, certain mycorrhizal mushroom species, such as *Lactarius deliciosus* (Saffron milk cap), can also be cultivated, although with limited success, through agroforestry integration (Wang et al., 2021). Mycorrhizal species host-specific to pine forests, such as *Suillus luteus* and *Rhizopogon roseolus*, have also shown high inoculation success, and their fructification has been integrated into various forest restoration projects (Santelices Moya et al., 2012; Shimomura et al., 2012). These achievements demonstrate that mycorrhizal species can be domesticated through long-term planning in association with appropriate host plants. Cultivating such species not only reduces the pressure on natural populations but also provides products that are available to consumers throughout the year.

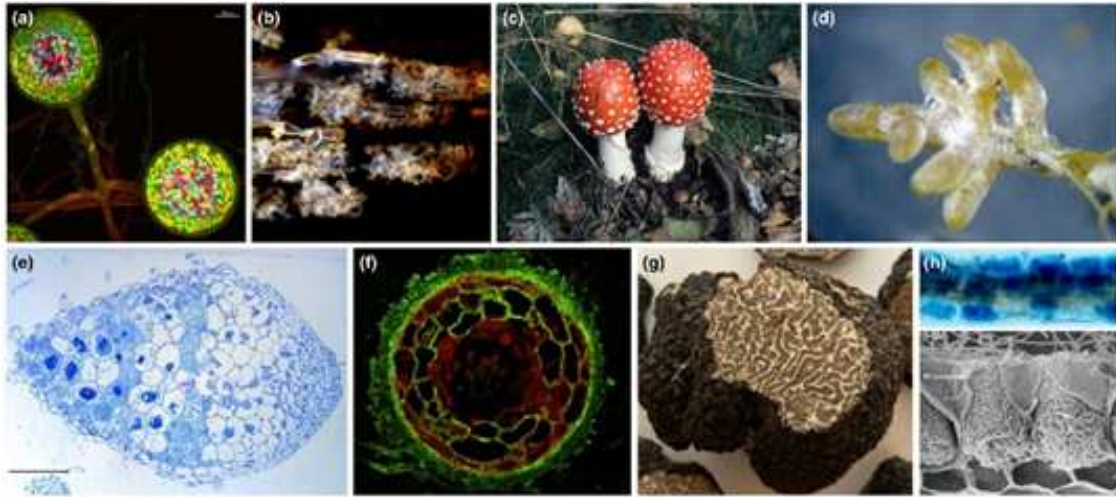


Figure 6 Typical structures of various types of mycorrhizal symbiosis (Martin & van der Heijden, 2024).

On the other hand, the majority of mycorrhizal fungi, which are very valuable to the food industry, have not yet been fully cultivated or can only be grown under semi-culture conditions due to the complexity of their natural life cycles. These fungi often form highly-specific and complex symbiotic associations with particular tree species (Figure 6). For example, globally renowned species such as porcino (*Boletus edulis*), chanterelle (*Cantharellus cibarius*), and grey knight (*Tricholoma terreum*) struggle to produce mycocarps in the absence of their ectomycorrhizal bonds with broadleaf or coniferous trees (Deshaware et al., 2021; Hall et al., 1998; Parladé et al., 2017; Straatsma & van Griensven, 1986). The primary obstacle in the domestication of species such as *B. edulis*, *Tricholoma matsutake* (matsutake), *C. cibarius*, *Russula vesca*, and *Amanita caesarea* is mainly due to the complexity of their symbiotic relationships (Deshaware et al., 2021; Oh & Lim, 2018; Parladé et al., 2017). Although mycelial production has been successfully achieved in the *Boletus* and *Russula* genera, the microbial environmental conditions and chemical signaling required for fructification have not yet been fully understood (Yamanaka et al., 2020). Experiments on matsutake have revealed that the fungus is influenced not only by its mycorrhizal association but also by volatile chemical signals (Volatile organic compounds, VOCs) in the soil and bacterial symbiosis (Oh & Lim, 2018). Consequently, these species are generally obtained through wild foraging, and their commercial availability remains dependent on seasonal and regional conditions. Semi-cultivation trials have focused on mimicking natural habitat conditions or supporting mycelial development; however, they have not yet led to full-scale, consistent commercial production. This situation limits the availability of these valuable mushrooms within the food industry and keeps their market prices high. For such species, the cultivation process remains experimental and requires long-term symbiosis research along with advanced techniques in soil biology.

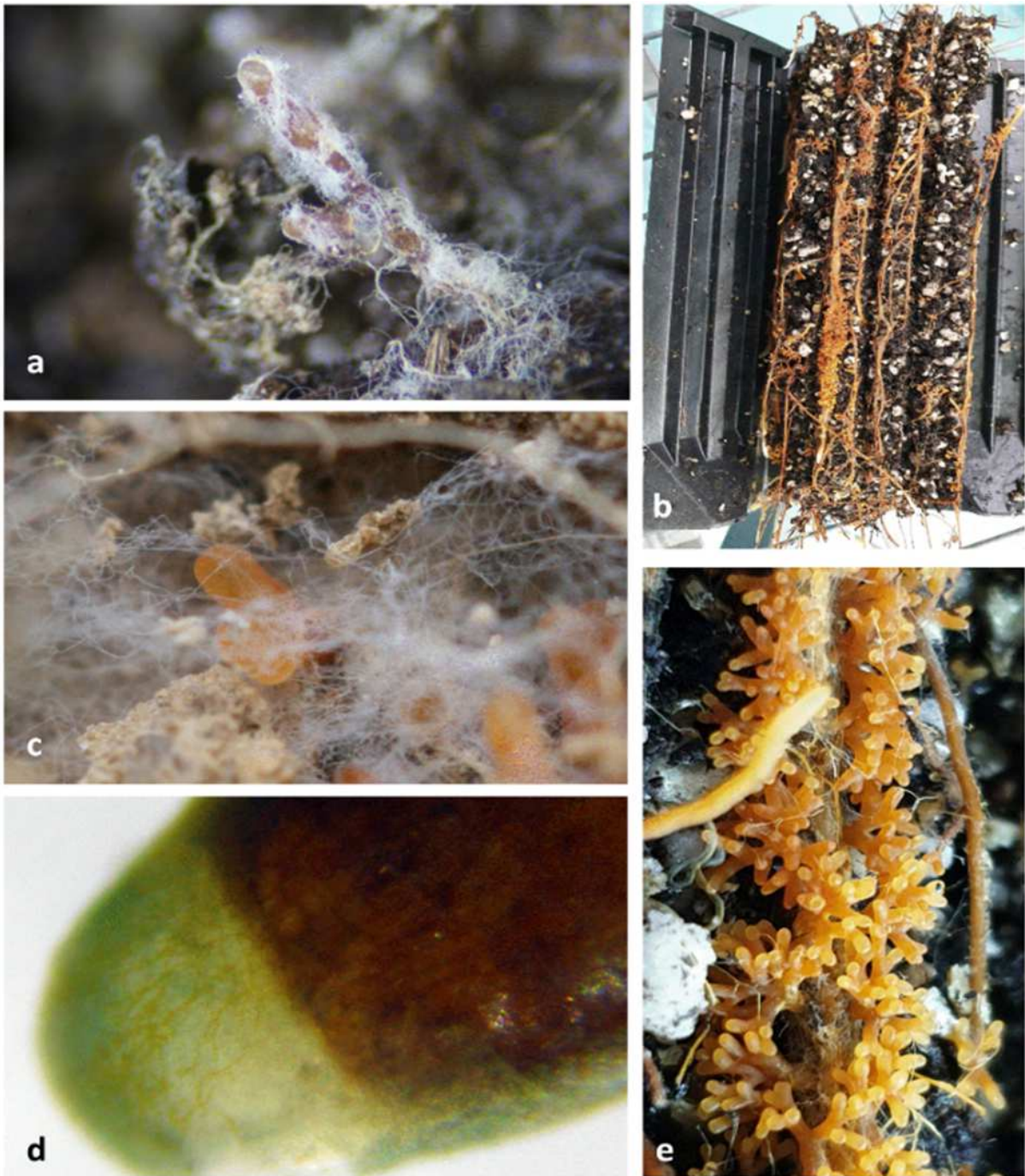


Figure 7 Mycorrhizae of *Lactarius deliciosus*. a) An aged mycorrhizal root section displaying white fungal hyphae attached to the orange mantle of *L. deliciosus* b) Extensively mycorrhized plants cultivated at Truffles and Mushrooms (Consulting) Limited facilities c) A single mycorrhizal root tip d) A solitary root tip showing hyphal growth toward the apex from the pigmented mantle e) Additional mycorrhized plant specimen from the same facility (Wang et al., 2021).

2.2.2. Cultivation Status of Mycorrhizal Fungi Valuable to the Pharmaceutical Industry

All medicinally and functionally valuable mycorrhizal mushrooms are also edible species with gastronomic uses, and some, such as *Hydnum repandum* (wood hedgehog), have not yet been domesticated, despite holding established ethnomycological significance (Çevrim, 2023; Yılmaz & Zencirci, 2015). Alongside their considerable gastronomic importance, truffles, most of which have been largely domesticated, are known to possess anti-inflammatory properties and are also considered potential sources of antitumor and immunomodulatory effects (Cicero et al., 2025). *Terfezia* species such as *T. arenaria* and *T. clavayi* (desert truffles), which have been domesticated through agroforestry integration like true truffles, are also of ethnomycological importance and have been investigated for their cardiovascular protective, antioxidant, antitumor, and immunomodulatory properties (Figure 8) (Morte et al., 2009, 2012; Veeraraghavan et al., 2022).



Figure 8 An example of an agroforestry integration method: an established truffle orchard (*A Beginner's Guide to Growing Truffles, Blog: Field & Forest Products, n.d.*).

While porcino and saffron milk cap mushrooms possess pharmacological value as dietary supplements, the grey knight also stands out for its various bioactive properties (Rosa et al., 2020; Sevindik et al., 2025). Likewise, *Hydnum repandum* (wood hedgehog) is known to exhibit antigenotoxic (DNA damage-preventing) and antimutagenic properties; *Sarcodon imbricatus* (scaly hedgehog) possesses antitumor and immunomodulatory effects, while *Cantharellus cibarius* (chanterelle) features all of these along with additional anti-inflammatory and therapeutic properties (Muszyńska et al., 2016; X. Tan et al., 2020; Tubic et al., 2019). All of these species, which are among the mushrooms with medicinal value that have not been cultivated, are also among the gastronomic mushrooms of ethnomycological importance (Çevrim, 2023; Yılmaz & Zencirci, 2015).



Figure 9 Illustration of Beefsteak fungus, *Fistulina hepatica*, by Carlo Vittadini (1835).

2.3. Cultivation Status of Parasitic Fungi

Fungi that survive on or in other living organisms by obtaining nutrients from the host organism are called parasitic fungi. These fungi are excessively difficult to cultivate and induce to form myocarps unless they possess saprotrophic transition capabilities. *Armillaria mellea* and *A. ostoyae* (Honey Fungus) are parasitic fungi that produce edible myocarps under appropriate conditions and hold significant value due to their medicinal properties (anti-aging, hepatoprotective, neuroprotective, and immunomodulatory), while also exhibiting biomaterial potential through their rhizomorph (root-like) mycelial specializations; however, they have not been fully domesticated (Ren et al., 2023). *Fistulina hepatica* (beefsteak fungus) is a nutritionally valuable species characterized by its liver-like morphology (Figure 9). Although mycelial cultures can be established, the failure to produce myocarps is predicted to result from complex signaling (VOCs) with its host (Ransdell, 2012; Wu et al., 2007). While gourmet species like *Hypomyces lactifluorum* (lobster mushroom) and medicinal fungi such as *Inonotus obliquus* (Chaga) and *I. hispidus* may share similar cultivation challenges, saprotrophic–transitional mushrooms, such as *Fomes fomentarius* (tinder fungus) and the ant-pathogenic (host-killing) *Cordyceps militaris*, can be successfully cultivated (Das et al., 2010; Hanlin, 1963; Lee & Yun, 2011; Pohl et al., 2022). In this way, tinder fungus can be widely used both in biomaterial production and in the pharmaceutical industry, and *C. militaris* can be widely used in pharmacology and functional food. However, it is predicted that the difficulty of culturing *Ophiocordyceps sinensis*, which has a similar ecology to *C. militaris*, is not related to signaling but only to the choice of prey (Krishna et al., 2025).

Table 1 Cultivation status of mushrooms that grow in Turkey and have ethnomycological value locally and globally (Çevrim, 2023; Yılmaz & Zencirci, 2015).

#	Scientific Name	Turkish (Local) Name	English Common Name(s)	Ecological Role	Cultivation Status
Cultivation Status: Cultivated					Count: 8
1	<i>Agaricus bisporus</i>	Kültür mantarı	Button Mushroom	Saprophytic	Cultivated
2	<i>Flammulina velutipes</i>	Tüylü bacak	Velvet Shank (Wild Enoki)	Saprophytic	Cultivated
3	<i>Ganoderma lucidum</i>	Reishi mantarı	Reishi Mushroom (Varnished Conk)	Parasitic/Saprophytic	Cultivated
4	<i>Grifola frondosa</i>	Maitake	Hen-of-the-Woods (Maitake)	Saprophytic/Parasitic	Cultivated
5	<i>Laetiporus sulphureus</i>	Kükürt mantarı	Chicken-of-the-Woods (Sulphur Polypore)	Saprophytic/Parasitic	Cultivated
6	<i>Pleurotus eryngii</i>	Çakşır mantarı, Kral istridye	King Oyster (King Trumpet) Mushroom	Saprophytic	Cultivated
7	<i>Pleurotus ostreatus</i>	İstiridye mantarı, Kavak mantarı	Oyster Mushroom	Saprophytic	Cultivated
8	<i>Lactarius deliciosus</i>	Kanlıca mantarı, Melki, Çıntar	Saffron Milk Cap (Red Pine Mushroom)	Mycorrhizal	Cultivated
Cultivation Status: Wild Foraging					Count: 28
9	<i>Agaricus campestris</i>	Çayır mantarı, Evelek	Meadow Mushroom	Saprophytic	Wild Foraging
10	<i>Agaricus bitorquis</i>	Tarla mantarı	Pavement Mushroom	Saprophytic	Wild Foraging
11	<i>Amanita caesarea</i>	İmparator mantarı	Caesar's Mushroom	Mycorrhizal	Wild Foraging
12	<i>Boletus badius</i>	Kahverengi Bolet	Bay Bolete	Mycorrhizal	Wild Foraging
13	<i>Boletus edulis</i>	Porçini, Çörek mantarı	Porcino (Penny Bun, King Bolete)	Mycorrhizal	Wild Foraging
14	<i>Bovista plumbea</i>	Puf mantarı	Tumbling Puffball	Saprophytic	Wild Foraging
15	<i>Calocybe gambosa</i>	Mayhoş mantarı	St. George's Mushroom	Saprophytic	Wild Foraging
16	<i>Cantharellus cibarius</i>	Kazayağı (Sarıköz) mantarı	Golden Chanterelle (Girole)	Mycorrhizal	Wild Foraging
17	<i>Chroogomphus rutilus</i>	Kızıl Telkoparan	Copper Spike (Brown Slimecap)	Mycorrhizal	Wild Foraging
18	<i>Clitocybe geotropa</i>	Hunili Mantar	Trooping Funnel (Monk's Head)	Saprophytic	Wild Foraging
19	<i>Coprinus comatus</i>	Mürekkep mantarı	Shaggy Ink Cap (Lawyer's Wig, Shaggy Mane)	Saprophytic	Wild Foraging

20	Craterellus cornucopioides	Borazan mantarı	Black Trumpet (Trumpet of the Dead)	Saprophytic	Wild Foraging
21	Craterellus tubaeformis	Borazan mantarı	Winter (Funnel) Chanterelle (Yellowfoot)	Mycorrhizal/Saprophytic	Wild Foraging
22	Hericium coralloides	Mercan Mantarı	Coral Tooth Fungus (Comb Coral Mushroom)	Saprophytic/Parasitic	Wild Foraging
23	Hydnum repandum	Sığırdili mantarı	Hedgehog Mushroom (Wood Hedgehog)	Mycorrhizal	Wild Foraging
24	Lactarius glyciosmus	Hindistancevizi Sütlüsü	Coconut Scented Milk Cap	Mycorrhizal	Wild Foraging
25	Lactarius piperatus	Acı Sütü Mantar	Peppery Milk Cap	Mycorrhizal	Wild Foraging
26	Lactarius salmonicolor	Göknar kanlıcası, Kanlıca mantarı	Salmon Milk Cap (Milky Agaric, Blood Fungus)	Mycorrhizal	Wild Foraging
27	Lactarius volemus	Sütü Mantar	Fishy Milkcap (Weeping Milk Cap)	Mycorrhizal	Wild Foraging
28	Lepista nuda	Mavi Cincile	Wood Blewit (Blewit)	Saprophytic	Wild Foraging
29	Macrolepiota procera	Şemsiye mantarı, Turna bacağı	Parasol Mushroom	Saprophytic	Wild Foraging
30	Marasmius oreades	Peri halkası mantarı	Fairy Ring Mushroom	Saprophytic	Wild Foraging
31	Ramaria botrytis	Karnabahar Mantarı	Cauliflower Coral	Mycorrhizal	Wild Foraging
32	Ramaria flava	Sarı Mercan Mantarı	Yellow Coral Fungus (Goat's Beard)	Mycorrhizal	Wild Foraging
33	Russula chloroides	Kayışkırın mantarı	Blue Band Brittlegill	Mycorrhizal	Wild Foraging
34	Russula delicata	Koç mantarı	Milk-White Brittlegill	Mycorrhizal	Wild Foraging
35	Tricholoma anatolicum	Katranmantarı	Anatolian Matsutake	Mycorrhizal	Wild Foraging
36	Tricholoma terreum	Karakız mantarı	Grey Knight (Dirty Tricholoma)	Mycorrhizal	Wild Foraging
Cultivation Status: Semi-Cultivated					Count: 6
37	Terfezia arenaria	Domalan	Desert Truffle	Mycorrhizal	Semi- Cultivated
38	Tuber aestivum	Yaz trüfü	Summer Truffle (Burgundy Truffle)	Mycorrhizal	Semi- Cultivated
39	Tuber macrosporum	Koca trüf	Smooth Black Truffle	Mycorrhizal	Semi- Cultivated
40	Morchella angusticeps	Kuzugöbeği	Common Eastern Black Morel	Mycorrhizal/Saprophytic	Semi- Cultivated
41	Morchella elata	Kuzugöbeği	Black Morel	Mycorrhizal/Saprophytic	Semi- Cultivated
42	Morchella esculenta	Kuzugöbeği	Common (Yellow or True) Morel	Mycorrhizal/Saprophytic	Semi- Cultivated

3. The Utilization Potentials of Wild Mushrooms

3.1. Potentials in the Research of Biotechnology and Scientific

The crucial role of mushrooms in natural decomposition has made them increasingly important in addressing pollution problems caused by the accumulation of non-biodegradable materials in the modern era. Using the mycelial structures of species such as oyster, king oyster (*Pleurotus eryngii*, commonly known as çakşır mushroom), and reishi, it is possible to produce biodegradable, lightweight, durable, and flexible biomaterials (Sun et al., 2022; Zitte et al., 2012). Additionally, the fibrous structures of certain species like *Fomes fomentarius* (hoof fungus) offer a sustainable alternative to traditional animal leather in the production of synthetic leather (Pohl et al., 2022). Similarly, panels derived from fungal mycelium can be utilized for thermal and acoustic insulation in buildings. Notably, biomaterials cultivated by growing oyster mushrooms on petroleum waste have contributed to the development of eco-friendly packaging materials, comparable to styrofoam or usable as biofilm, providing sustainable alternatives to petrochemical-based packaging (Srivastava et al., 2025). Furthermore, *Trametes versicolor* has been used in the biodegradation and remediation of textile waste, wastewater, and pesticides, while *Phanerochaete chrysosporium* has demonstrated potential in the biodegradation of pathogenic proteins and pesticides; also, the resulting fungal biomass is also seen as a promising source for biofuel production (Beltrán-Flores et al., 2021; Paszczynski & Crawford, 1995; Ryan et al., 2007; Srivastava et al., 2025).

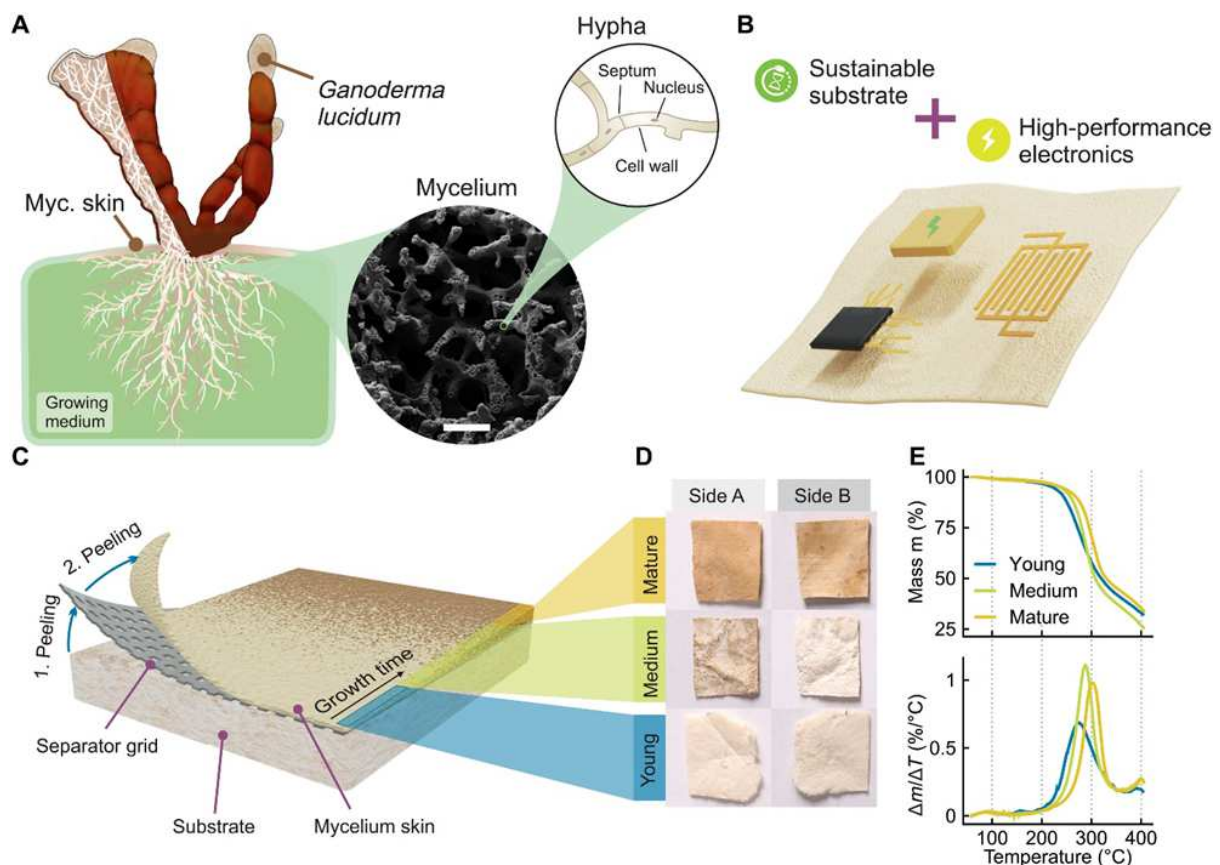


Figure 10 Morphological features of *Ganoderma lucidum* and its material structure applicable to sustainable electronic technologies (Danninger et al., 2022).

Coprinus cinerea is one of the most commonly used model organisms in studies aimed at understanding the sporulation physiology of basidiomycetes (Meškauskas et al., 1998). For instance, *Coprinus cinerea* plays a critical role in understanding the gravitropism of certain basidiomycetes, particularly species like oyster mushrooms that have gained significance in space nutrition due to their ease of cultivation, oxygen processing capacity, and nutrient content such as vitamin D, which may be beneficial for astronauts (Bunyard, 2012; Kovalev et al., 2022; Meškauskas et al., 1998; Moore, 1996). *Cordyceps* species, known for their entomoparasitic features, have been extensively studied in relation to the biosynthesis of bioactive compounds like cordycepin, host behavior manipulation, and pharmaceutical applications (L. Tan et al., 2021). Alongside *Cordyceps*, another species used in fungal computing studies is *Schizophyllum commune*, which has served as a model in fundamental mycological research on hyphal communication, mating types, and cell-to-cell recognition processes. It also holds importance in enzyme production and microbial interaction studies (Palmer & Horton, 2006). Research by Adamatzky on fungal computing has demonstrated that fungi exhibit signal transmission through electrical impulses and language-like complex systems of communication (Adamatzky, 2018, 2022; Dehshibi & Adamatzky, 2021). However, the relationship between such signaling processes and symbiosis remains unclear and warrants further investigation. Additionally, studies have been conducted on the potential of *Ganoderma lucidum* mycelium for applications in sustainable electronics (Figure 10)(Danninger et al., 2022).

3.2. Potentials in the Field of Food and Gastronomy

The production and diversification strategies of the food industry are largely shaped by local consumption patterns and regional supply-demand dynamics. The case of Türkiye exemplifies a pattern that is also observable globally: cultivated mushrooms currently consumed are predominantly species with established ethnomycological significance (Çevrim, 2023; Royse et al., 2017; Stabnikova et al., 2024; Yılmaz & Zencirci, 2015). Despite the wide range of mushroom species with ethnomycological importance in Türkiye, the number of species actually consumed remains rather limited. Only a small fraction of mushrooms with ethnomycological value have been domesticated, and among those, an even smaller portion is produced at an industrially efficient scale. This gap reveals significant potential for expanding cultivation efforts, offering opportunities from local to global scales. While some wild-foraged, non-domesticated, species remain uncultivated due to inherent challenges in domestication, a significant portion lacks dedicated research on domestication protocols (Çevrim, 2023; Yılmaz & Zencirci, 2015). Nevertheless, species such as *Lactarius* spp., *F. hepatica*, and *H. lactifluorum* exhibit significant potential as vegan or alternative food sources (Hanlin, 1963; Wang et al., 2021; Wu et al., 2007).

4. Discussion

The economic potential of mushrooms has been increasingly recognized in both the food and biotechnology sectors. However, the complexity of domestication processes continues to present serious technical and ecological limitations, particularly in mycorrhizal species. Advancing technology and research insights have shown that ecological limitations are not only due to abiotic factors or nutrients but may also result from complex interspecific interactions; understanding intraspecific and interspecific signaling represents a scientific advancement that could support the cultivation of parasitic and mycorrhizal species. The cultivation of such species and saprotrophic mushrooms that remain understudied or whose requirements are not fully characterized holds significant market potential. This potential would allow wild mushrooms, which currently constitute only 8% of total consumption,

to become more widely accessible and consumed, mirroring trends seen in other cultivated species; while simultaneously protecting their natural populations from overharvesting pressures despite their current low utilization (Krishna et al., 2025; Zotti et al., 2013).

Expanding the range of cultivated species would represent a breakthrough that could not only introduce an entire biological kingdom more extensively into gastronomy but also lay the groundwork for further scientific research. Through deciphering signaling-symbiosis relationships among species, we can unlock possibilities ranging from fundamental research, such as modeling signaling networks within forest ecosystems or expanding the spectrum of cultivable species, to applied studies in radioactive mycoremediation and space agriculture, and even fringe scientific breakthroughs like self-regenerating fungal artificial intelligence (Adamatzky, 2018; Chatterjee et al., 2017; Van Der Heijden & Hortan, 2009). A more immediate benefit of diversifying mushroom cultivation would be the ability to thoroughly study species' ecological requirements and survival thresholds under controlled laboratory conditions. The incorporation of these findings into the literature could establish the necessary infrastructure to model distribution patterns, using tools like microclima, ERA5, and NicheMapR, under current climate conditions, extreme environments, and various future climate change scenarios, while predicting threat levels (Kearney & Porter, 2017; Klinges et al., 2022). This potential demonstrates that mushroom domestication processes hold strategic importance not only for commercial applications and biotechnological innovation, but equally for enhancing ecosystem resilience and the conservation of threatened species.

Preprint Statement

A preprint has previously been published (Dıblan & Cabi, 2025).

Ethical Statement

There is no need to obtain permission from the ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest between us as the article authors.

Authorship Contribution Statement

Concept: E.C., S.D.; Design: S.D.; Data Collection or Processing: S.D.; Literature Search: S.D.; Writing, Review, and Editing: S.D.; Supervising: E.C.

References

- A Beginner's Guide to Growing Truffles, Blog: Field & Forest Products*. (n.d.). Retrieved June 27, 2025, from <https://www.fieldforest.net/product/truffle-growing-guide/BLOG>
- Adamatzky, A. (2018). Towards fungal computer. *Interface Focus*, 8(6), 20180029. <https://doi.org/10.1098/rsfs.2018.0029>
- Adamatzky, A. (2022). Language of fungi derived from their electrical spiking activity. *Royal Society Open Science*, 9(4), 211926. <https://doi.org/10.1098/rsos.211926>
- Ajibola, O. O., Nolasco-Hipolito, C., Carvajal-Zarrabal, O., Salleh, S. F., Adeyinka, G. C., Adefegha, S. A., Ahmmed, M. K., Sumaiya, K., & Thomas, R. (2024). Turkey tail mushroom (*Trametes versicolor*): An

- edible macrofungi with immense medicinal properties. *Current Opinion in Food Science*, 58, 101191.
- Beltrán-Flores, E., Sarrà, M., & Blánquez, P. (2021). Pesticide bioremediation by *Trametes versicolor*: Application in a fixed-bed reactor, sorption contribution and bioregeneration. *Science of The Total Environment*, 794, 148386. <https://doi.org/10.1016/j.scitotenv.2021.148386>
- Buko, V., Bakunovich, A., Astrowski, A., Moroz, V., Puchkova, T., Kastsianeovich, A., & Tomulewicz, M. (2019). Polysaccharides of mushroom *Phallus impudicus* mycelium: Immunomodulating and wound healing properties. *现代食品科技*, 35(9), 30–37.
- Bunyard, B. A. (2012). *Mushroom Gravitropism*. http://fungimag.com/fall-2012-articles_2/FallV5I4SGravitropismLR.pdf
- Burge, H. A., & Otten, J. A. (1990). Fungi. *ASTM Special Technical Publication*, 1071, 136–162.
- Cavalier-Smith, T. (2001). What are Fungi? In D. J. McLaughlin, E. G. McLaughlin, & P. A. Lemke (Eds.), *Systematics and Evolution* (pp. 3–37). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-10376-0_1
- Çevrim, M. (2023). *Konya İlinde Halk Tarafından Değerlendirilen Makrofunguslar ve Etnomikolojik Özelliklerinin Araştırılması*. <https://acikerisim.selcuk.edu.tr/items/5a052278-e9fe-44ca-be91-0f110082fdfa>
- Chang, S. T., Li, G. S. F., & Peberdy, J. F. (1985). Isolation of protoplasts from edible fungi. *World Journal of Microbiology and Biotechnology*, 1(2), 185–193.
- Chang, S. T., & Miles, P. G. (1987). Historical record of the early cultivation of *Lentinus* in China. *Mushroom Journal of the Tropics*, 7, 31–37.
- Chang, S.-T., & Miles, P. G. (2004). *Mushrooms: Cultivation, nutritional value, medicinal effect and environmental impact* (2. ed). CRC Pr.
- Chatterjee, S., Sarma, M. K., Deb, U., Steinhäuser, G., Walther, C., & Gupta, D. K. (2017). Mushrooms: From nutrition to mycoremediation. *Environmental Science and Pollution Research*, 24(24), 19480–19493. <https://doi.org/10.1007/s11356-017-9826-3>
- Chevalier, G. (1973). *Axenic synthesis of mycorrhiza of *Tuber brumale* Vitt. From pure fungal cultures*. <https://www.cabidigitallibrary.org/doi/full/10.5555/19741312585>
- Cicero, I., Mirabile, G., & Venturella, G. (2025). Potential Medicinal Fungi from Freshwater Environments as Resources of Bioactive Compounds. *Journal of Fungi*, 11(1), Article 1. <https://doi.org/10.3390/jof11010054>
- Coleman, M. D., Berch, S., Bonito, G., Allen, B., Andrews, E., Arechiga Carvajal, E. T., Cook, S. P., D'Amours, C., Garibay-Orijel, R., Guevara, G., Hatzenbuehler, P., Hawkins, B., Heinse, R., Kernaghan, G., Lefevre, C., Lemmond, B., Meadows, I. M., Oneto, S., Sharma, J., ... Smith, M. E. (2025). Status of truffle science and cultivation in North America. *Plant and Soil*, 508(1), 625–661. <https://doi.org/10.1007/s11104-024-06822-4>

- Cooke, M. C. (1871). Polymorphic Fungi. *The American Naturalist*, 5(7), 400–412.
<https://doi.org/10.1086/270800>
- Danninger, D., Pruckner, R., Holzinger, L., Koepe, R., & Kaltenbrunner, M. (2022). MycelioTronics: Fungal mycelium skin for sustainable electronics. *Science Advances*, 8(45), eadd7118.
<https://doi.org/10.1126/sciadv.add7118>
- Das, S. K., Masuda, M., Sakurai, A., & Sakakibara, M. (2010). Medicinal uses of the mushroom *Cordyceps militaris*: Current state and prospects. *Fitoterapia*, 81(8), 961–968.
<https://doi.org/10.1016/j.fitote.2010.07.010>
- Dehshibi, M. M., & Adamatzky, A. (2021). Electrical activity of fungi: Spikes detection and complexity analysis. *Biosystems*, 203, 104373. <https://doi.org/10.1016/j.biosystems.2021.104373>
- Deshaware, S., Marathe, S. J., Bedade, D., Deska, J., & Shamekh, S. (2021). Investigation on mycelial growth requirements of *Cantharellus cibarius* under laboratory conditions. *Archives of Microbiology*, 203(4), 1539–1545. <https://doi.org/10.1007/s00203-020-02142-0>
- Díaz-Talamantes, C., Burrola-Aguilar, C., Aguilar-Miguel, X., Mata, G., Díaz-Talamantes, C., Burrola-Aguilar, C., Aguilar-Miguel, X., & Mata, G. (2017). In vitro mycelial growth of wild edible mushrooms from the central Mexican highlands. *Revista Chapingo Serie Ciencias Forestales y Del Ambiente*, 23(3), 369–383.
<https://doi.org/10.5154/r.rchscfa.2016.12.067>
- Diblan, S., & Cabi, E. (2025) *Ecological Roles and Biotechnological Potential of Wild Mushroom Cultivation*. Research Square. [Preprint]. (Version 1) 07 October 2025 [cited 2025 Oct 14] Available from:
<https://doi.org/10.21203/rs.3.rs-7791958/v1>
- Ferenczy, L. (1981). Microbial protoplast fusion. *Genetics as a Tool in Microbiology*, 1–34.
- Gao, Y., Chan, E., & Zhou, S. (2004). Immunomodulating Activities of *Ganoderma*, a Mushroom with Medicinal Properties. *Food Reviews International*, 20(2), 123–161. <https://doi.org/10.1081/FRI-120037158>
- Gao, Z., Kong, D., Cai, W., Zhang, J., & Jia, L. (2021). Characterization and anti-diabetic nephropathic ability of mycelium polysaccharides from *Coprinus comatus*. *Carbohydrate Polymers*, 251, 117081.
- Goltapeh, E. M., Danesh, Y. R., Prasad, R., & Varma, A. (2008). Mycorrhizal Fungi: What We Know and What Should We Know? In A. Varma (Ed.), *Mycorrhiza: State of the Art, Genetics and Molecular Biology, Eco-Function, Biotechnology, Eco-Physiology, Structure and Systematics* (pp. 3–27). Springer.
https://doi.org/10.1007/978-3-540-78826-3_1
- Griffiths, A. J. (1992). Fungal senescence. *Annual Review of Genetics*, 26(1), 351–372.
- Hall, I. R., Lyon, A. J. E., Wang, Y., & Sinclair, L. (1998). Ectomycorrhizal fungi with edible fruiting bodies 2. *Boletus edulis*. *Economic Botany*, 44–56.
- Hanlin, R. T. (1963). Morphology of *Hypomyces lactifluorum*. *Botanical Gazette*.
<https://doi.org/10.1086/336225>

- Honegger, R. (1996). Structural and Functional Aspects of Mycobiont—Photobiont Relationships in Lichens Compared with Mycorrhizae and Plant Pathogenic Interactions. In M. Nicole & V. Gianinazzi-Pearson (Eds.), *Histology, Ultrastructure and Molecular Cytology of Plant-Microorganism Interactions* (Vol. 7, pp. 157–176). Springer Netherlands. https://doi.org/10.1007/978-94-009-0189-6_9
- Huang, K., Li, L., Wu, W., Pu, K., Qi, W., Qi, J., & Li, M. (2024). Enhancing Morchella Mushroom Yield and Quality Through the Amendment of Soil Physicochemical Properties and Microbial Community with Wood Ash. *Microorganisms*, *12*(12), Article 12. <https://doi.org/10.3390/microorganisms12122406>
- Jang, M.-J., Lee, Y.-H., Liu, J.-J., & Ju, Y.-C. (2009). Optimal Conditions for the Mycelial Growth of *Coprinus comatus* Strains. *Mycobiology*, *37*(2), 103–108. <https://doi.org/10.4489/MYCO.2009.37.2.103>
- Jo, W.-S., Cho, Y.-J., Cho, D.-H., Park, S.-D., Yoo, Y.-B., & Seok, S.-J. (2009). Culture Conditions for the Mycelial Growth of *Ganoderma applanatum*. *Mycobiology*, *37*(2), 94–102. <https://doi.org/10.4489/MYCO.2009.37.2.094>
- Jong, S. C., & Birmingham, J. M. (1992). Medicinal Benefits of the Mushroom *Ganoderma*. In S. L. Neidleman & A. I. Laskin (Eds.), *Advances in Applied Microbiology* (Vol. 37, pp. 101–134). Academic Press. [https://doi.org/10.1016/S0065-2164\(08\)70253-3](https://doi.org/10.1016/S0065-2164(08)70253-3)
- Kalac, P. (2001). A review of edible mushroom radioactivity. *Food Chemistry*, *75*, 29–35. [https://doi.org/10.1016/S0308-8146\(01\)00171-6](https://doi.org/10.1016/S0308-8146(01)00171-6)
- Kalenius, R. (2022). *Mushroom cultivation in Temperate Agroforestry*.
- Kearney, M. R., & Porter, W. P. (2017). NicheMapR – an R package for biophysical modelling: The microclimate model. *Ecography*, *40*(5), 664–674. <https://doi.org/10.1111/ecog.02360>
- Keyes, A. A., McLaughlin, J. P., Barner, A. K., & Dee, L. E. (2021). *An ecological network approach to predict ecosystem service vulnerability to species losses*. <https://doi.org/10.1038/s41467-021-21824-x>
- Klinges, D. H., Duffy, J. P., Kearney, M. R., & Maclean, I. M. D. (2022). mcera5: Driving microclimate models with ERA5 global gridded climate data. *Methods in Ecology and Evolution*, *13*(7), 1402–1411. <https://doi.org/10.1111/2041-210X.13877>
- Kovalev, V. S., Grandl, W., Manukovsky, N. S., Tikhomirov, A. A., & Böck, C. (2022). Modeling a lunar base mushroom farm. *Life Sciences in Space Research*, *33*, 1–6. <https://doi.org/10.1016/j.lssr.2021.12.005>
- Krishna, K. V., Balasubramanian, B., Park, S., Bhattacharya, S., Kadanthottu Sebastian, J., Liu, W.-C., Pappuswamy, M., Meyyazhagan, A., Kamyab, H., Chelliapan, S., & Malaviya, A. (2025). Conservation of Endangered *Cordyceps sinensis* Through Artificial Cultivation Strategies of *C. militaris*, an Alternate. *Molecular Biotechnology*, *67*(4), 1382–1397. <https://doi.org/10.1007/s12033-024-01154-1>
- Kupcova, K., Stefanova, I., Plavcova, Z., Hosek, J., Hrouzek, P., & Kubec, R. (2018). Antimicrobial, cytotoxic, anti-inflammatory, and antioxidant activity of culinary processed Shiitake medicinal mushroom (*Lentinus edodes*, Agaricomycetes) and its major sulfur sensory-active compound- Lenthionine. *International Journal of Medicinal Mushrooms*, *20*(2).

- <https://www.dl.begellhouse.com/journals/708ae68d64b17c52,6866212879aab21d,598faaed030c0bf7.html>
- Kuznetsov, A. I. (2010). *Method of cultivation of mushroom phallus impudicus* (Patent No. RU2386239C2).
<https://patents.google.com/patent/RU2386239C2/en>
- Landingin, H. R. R., Francisco, B. E., Dulay, R. M. R., Kalaw, S., & Reyes, R. (2020). Optimization of Culture Conditions for Mycelial Growth and Basidiocarp Production of *Cyclocybe cylindracea* (Maire). *CLSU International Journal of Science & Technology*, 4(1), Article 1. <https://doi.org/10.22137/ijst.2020.v4n1.01>
- Lee, I.-K., & Yun, B.-S. (2011). Styrylpyrone-class compounds from medicinal fungi *Phellinus* and *Inonotus* spp., and their medicinal importance. *The Journal of Antibiotics*, 64(5), 349–359.
- Martin, F. M., & van der Heijden, M. G. A. (2024). The mycorrhizal symbiosis: Research frontiers in genomics, ecology, and agricultural application. *New Phytologist*, 242(4), 1486–1506.
<https://doi.org/10.1111/nph.19541>
- Mayuzumi, Y., & Mizuno, T. (1997). III. Cultivation methods of maitake (*Grifola frondosa*). *Food Reviews International*, 13(3), 357–364. <https://doi.org/10.1080/87559129709541117>
- Meškauaskas, A., Moore, D., & Frazer, L. N. (1998). Mathematical modelling of morphogenesis in fungi: Spatial organization of the gravitropic response in the mushroom stem of *Coprinus cinereus*. *The New Phytologist*, 140(1), 111–123. <https://doi.org/10.1046/j.1469-8137.1998.00252.x>
- Moore, D. (1996). Gravitropism in fungi. *Advances in Space Research*, 17(6), 73–82.
[https://doi.org/10.1016/0273-1177\(95\)00614-K](https://doi.org/10.1016/0273-1177(95)00614-K)
- Morte, A., Andriano, A., Honrubia, M., & Navarro-Ródenas, A. (2012). Terfezia Cultivation in Arid and Semiarid Soils. In A. Zambonelli & G. M. Bonito (Eds.), *Edible Ectomycorrhizal Mushrooms: Current Knowledge and Future Prospects* (pp. 241–263). Springer. https://doi.org/10.1007/978-3-642-33823-6_14
- Morte, A., Zamora, M., Gutiérrez, A., & Honrubia, M. (2009). Desert Truffle Cultivation in Semiarid Mediterranean Areas. In C. Azcón-Aguilar, J. M. Barea, S. Gianinazzi, & V. Gianinazzi-Pearson (Eds.), *Mycorrhizas—Functional Processes and Ecological Impact* (pp. 221–233). Springer.
https://doi.org/10.1007/978-3-540-87978-7_15
- Muszyńska, B., Kała, K., Firlej, A., & Sułkowska-Ziaja, K. (2016). “*Cantharellus cibarius*”: Culinary-medicinal mushroom content and biological activity. <https://ruj.uj.edu.pl/xmlui/handle/item/137968>
- Oh, S.-Y., & Lim, Y. W. (2018). Root-associated bacteria influencing mycelial growth of *Tricholoma matsutake* (pine mushroom). *Journal of Microbiology*, 56(6), 399–407. <https://doi.org/10.1007/s12275-018-7491-y>
- Organic Shiitake Mushroom Plug Spawn*. (n.d.). La Mycosphère. Retrieved May 26, 2025, from <https://lamycosphere.com/en-fr/products/mycelium-shiitakes-on-wooden-dowels>
- Palmer, G. E., & Horton, J. S. (2006). Mushrooms by magic: Making connections between signal transduction and fruiting body development in the basidiomycete fungus *Schizophyllum commune*. *FEMS Microbiology Letters*, 262(1), 1–8. <https://doi.org/10.1111/j.1574-6968.2006.00341.x>

- Parladé, J., Martínez-Peña, F., & Pera, J. (2017). Effects of forest management and climatic variables on the mycelium dynamics and sporocarp production of the ectomycorrhizal fungus *Boletus edulis*. *Forest Ecology and Management*, 390, 73–79. <https://doi.org/10.1016/j.foreco.2017.01.025>
- Paszczynski, A., & Crawford, R. L. (1995). Potential for Bioremediation of Xenobiotic Compounds by the White-Rot Fungus *Phanerochaete chrysosporium*. *Biotechnology Progress*, 11(4), 368–379. <https://doi.org/10.1021/bp00034a002>
- Patel, Y., Naraian, R., & Singh, V. K. (2012). Medicinal properties of *Pleurotus* species (oyster mushroom): A review. *World Journal of Fungal and Plant Biology*, 3(1), 1–12.
- Pekşen, A., & Kibar, B. (2017). Investigations on the Cultivation of Wild Edible Mushroom *Macrolepiota procera*. *Uluslararası Tarım ve Yaban Hayatı Bilimleri Dergisi*, 3(2), Article 2. <https://doi.org/10.24180/ijaws.356549>
- Pinto, S., Barros, L., Sousa, M. J., & Ferreira, I. C. F. R. (2013). Chemical characterization and antioxidant properties of *Lepista nuda* fruiting bodies and mycelia obtained by *in vitro* culture: Effects of collection habitat and culture media. *Food Research International*, 51(2), 496–502. <https://doi.org/10.1016/j.foodres.2013.01.009>
- Pohl, C., Schmidt, B., Nunez Guitar, T., Klemm, S., Gusovius, H.-J., Platzk, S., Kruggel-Emden, H., Klunker, A., Völlmecke, C., Fleck, C., & Meyer, V. (2022). Establishment of the basidiomycete *Fomes fomentarius* for the production of composite materials. *Fungal Biology and Biotechnology*, 9(1), 4. <https://doi.org/10.1186/s40694-022-00133-y>
- Puia, I. C., Puia, A., Chedea, V. S., Leopold, N., Bocsan, I. C., & Buzoianu, A. D. (2018). Characterization of *Trametes versicolor*: Medicinal mushroom with important health benefits. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 46(2), 343–349.
- Ransdell, A. S. (2012). *Investigating the biosynthetic pathways to polyacetylenic natural products in *Fistulina hepatica* and *Echinacea purpurea**. Purdue University. <https://search.proquest.com/openview/0412ae5aad12b67db022113659c761dd/1?pq-origsite=gscholar&cbl=18750>
- Regis, M. A. J., & Geösel, A. (2023). Cultivation of *Auricularia* species: A review of the history, health benefits, principles, practices, environmental conditions, research methods, and recent trends. *Sydowia*, 76, 21–33. <https://doi.org/10.12905/0380.sydowia76-2024-0021>
- Ren, S., Gao, Y., Li, H., Ma, H., Han, X., Yang, Z., & Chen, W. (2023). Research Status and Application Prospects of the Medicinal Mushroom *Armillaria mellea*. *Applied Biochemistry and Biotechnology*, 195(5), 3491–3507. <https://doi.org/10.1007/s12010-022-04240-9>
- Reyna, S., & Garcia-Barreda, S. (2014). Black truffle cultivation: A global reality. *Forest Systems*, 23(2), Article 2. <https://doi.org/10.5424/fs/2014232-04771>
- Richards, T. A., Leonard, G., & Wideman, J. G. (2017). What Defines the “Kingdom” Fungi? In *The Fungal Kingdom* (pp. 57–77). John Wiley & Sons, Ltd. <https://doi.org/10.1128/9781555819583.ch3>

- Rosa, G. B., Sganzerla, W. G., Ferreira, A. L. A., Xavier, L. O., Veloso, N. C., Silva, J. da, Oliveira, G. P. de, Amaral, N. C., Veeck, A. P. de L., & Ferrareze, J. P. (2020). Investigation of Nutritional Composition, Antioxidant Compounds, and Antimicrobial Activity of Wild Culinary-Medicinal Mushrooms *Boletus edulis* and *Lactarius deliciosus* (Agaricomycetes) from Brazil. *International Journal of Medicinal Mushrooms*, 22(10). <https://doi.org/10.1615/IntJMedMushrooms.2020036347>
- Royse, D. J., Baars, J., & Tan, Q. (2017). Current Overview of Mushroom Production in the World. In C. Z. Diego & A. Pardo-Giménez (Eds.), *Edible and Medicinal Mushrooms* (1st ed., pp. 5–13). Wiley. <https://doi.org/10.1002/9781119149446.ch2>
- Ryan, D., Leukes, W., & Burton, S. (2007). Improving the bioremediation of phenolic wastewaters by *Trametes versicolor*. *Bioresource Technology*, 98(3), 579–587. <https://doi.org/10.1016/j.biortech.2006.02.001>
- Santelices Moya, R., Espinoza, S., Brunel, N., & Palfner, G. (2012). Effect of the geographical origin, culture media, and pH on the growth dynamic of the edible ectomycorrhizal mushroom *Suillus luteus*. *Ciencia e Investigación Agraria: Revista Latinoamericana de Ciencias de La Agricultura*, 39(2), 369–376.
- Sau-Wa Mak, V. (2024). Scientists and remaking heritage: The case of shiitake cultivation in a globally important agricultural heritage system in Japan. *International Journal of Heritage Studies*, 30(1), 42–55. <https://doi.org/10.1080/13527258.2023.2272255>
- Schmidt-Heydt, M., Magan, N., & Geisen, R. (2008). Stress induction of mycotoxin biosynthesis genes by abiotic factors. *FEMS Microbiology Letters*, 284(2), 142–149. <https://doi.org/10.1111/j.1574-6968.2008.01182.x>
- Senn-Irlet, B., Heilmann-Clausen, J., Genney, D., & Dahlberg, A. (2007). Guidance for conservation of macrofungi in Europe. *ECCF, Strasbourg*. <https://www.academia.edu/download/39279428/5578515308ae7521587033c2.pdf>
- Sevindik, M., Bal, C., Unal, O., & Eraslan, E. C. (2025). Bioactivity of the Gray Knight Mushroom *Tricholoma terreum* (Agaricomycetes): Antioxidant, Antiproliferative, and Enzyme Inhibition Potential. *International Journal of Medicinal Mushrooms*, 27(9). <https://doi.org/10.1615/IntJMedMushrooms.2025058982>
- Shah, S. R., Ukaegbu, C. I., Hamid, H. A., & Alara, O. R. (2018). Evaluation of antioxidant and antibacterial activities of the stems of *Flammulina velutipes* and *Hypsizygus tessellatus* (white and brown var.) extracted with different solvents. *Journal of Food Measurement and Characterization*, 12(3), 1947–1961. <https://doi.org/10.1007/s11694-018-9810-8>
- Shimomura, N., Matsuda, M., Ariyoshi, K., & Aimi, T. (2012). Development of mycelial slurries containing surfactant for cultivation of the edible ectomycorrhizal mushroom *Rhizopogon roseolus* (syn. *Rhizopogon rubescens*). *Botany*, 90(9), 839–844. <https://doi.org/10.1139/b2012-054>
- Simard, S. W., & Durall, D. M. (2004). Mycorrhizal networks: A review of their extent, function, and importance. *Canadian Journal of Botany*, 82(8), 1140–1165. <https://doi.org/10.1139/b04-116>
- Srivastava, S., Mathur, P., Prakash, P., Falletta, E., Katha, U., Pagani, A., Baranwal, A., Mishra, A., Zamboni, P., & Singh, A. V. (2025). Mushroom-Derived Innovations: Sustainable Biomaterials for Biomedical

- Engineering. *Biomedical Materials & Devices*, 3(1), 381–395. <https://doi.org/10.1007/s44174-024-00206-z>
- Stabnikova, O., Stabnikov, V., & Paredes-Lopez, O. (2024). Wild and cultivated mushrooms as food, pharmaceutical and industrial products. *Ukrainian Food Journal*, 13, 20–59. <https://doi.org/10.24263/2304-974X-2024-13-1-4>
- Stamets, P. (2004). The role of mushrooms in nature. *The Overstory Book: Cultivating Connections with Trees*, 2, 74–80.
- Straatsma, G., & van Griensven, L. J. (1986). Growth requirements of mycelial cultures of the mycorrhizal mushroom *Cantharellus cibarius*. *Transactions of the British Mycological Society*, 87(1), 135–141.
- Sun, C., Yue, P., Chen, R., Wu, S., Ye, Q., Weng, Y., Liu, H., & Fang, Y. (2022). Chitin-glucan composite sponge hemostat with rapid shape-memory from *Pleurotus eryngii* for puncture wound. *Carbohydrate Polymers*, 291, 119553.
- Tan, L., Song, X., Ren, Y., Wang, M., Guo, C., Guo, D., Gu, Y., Li, Y., Cao, Z., & Deng, Y. (2021). Anti-inflammatory effects of cordycepin: A review. *Phytotherapy Research*, 35(3), 1284–1297. <https://doi.org/10.1002/ptr.6890>
- Tan, X., Chen, W., Jiao, C., Liang, H., Yun, H., He, C., Chen, J., Ma, X., & Xie, Y. (2020). Anti-tumor and immunomodulatory activity of the aqueous extract of *Sarcodon imbricatus* in vitro and in vivo. *Food & Function*, 11(1), 1110–1121. <https://doi.org/10.1039/C9FO01230C>
- Thongbai, B., Rapior, S., Hyde, K. D., Wittstein, K., & Stadler, M. (2015). *Herichium erinaceus*, an amazing medicinal mushroom. *Mycological Progress*, 14(10), 91. <https://doi.org/10.1007/s11557-015-1105-4>
- Tiupova, A., Olędzki, R., & Harasym, J. (2025). Physicochemical, Functional, and Antioxidative Characteristics of Oyster Mushrooms. *Applied Sciences*, 15(3), Article 3. <https://doi.org/10.3390/app15031655>
- Tubic, J., Grujicic, D., Jakovljević, M., Ranković, B., Kosanić, M., Stanojković, T., Cirić, A., & Milošević-Djordjević, O. (2019). Investigation of biological activities and secondary metabolites of *Hydnum repandum* acetone extract. *Farmacia*. https://farmaciajournal.com/arhiva/201901/2019-01-art-24-Tubic_Milosevic-Djordjevic_174-183.pdf
- Van Der Heijden, M. G. A., & Hortal. (2009). Socialism in soil? The importance of mycorrhizal fungal networks for facilitation in natural ecosystems. *Journal of Ecology*.
- Veeraraghavan, V. P., Hussain, Sardar, Papayya Balakrishna, Janardhana, Dhawale, Lavina, Kullappan, Malathi, Mallavarapu Ambrose, Jenifer, & Krishna Mohan, S. (2022). A Comprehensive and Critical Review on Ethnopharmacological Importance of Desert Truffles: *Terfezia clavaryi*, *Terfezia boudieri*, and *Tirmania nivea*. *Food Reviews International*, 38(sup1), 846–865. <https://doi.org/10.1080/87559129.2021.1889581>
- Vittadini, C. (1835). *Descrizione dei funghi mangerecci più comuni dell'Italia e de' velenosi che possono co' medesimi confondersi*. Rusconi. <https://books.google.com/books?hl=tr&lr=&id=ZcJcAAAACAAJ&oi=fnd&pg=PP9&dq=+Descrizione+de>

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ts=BSSDoDAwes&sig=M2jJMR_dZW1HBSShs_jTtQSjJbc

- Wang, D., Zhang, J. L., Wang, Y., Zambonelli, A., Hall, I., & Xiong, W.-P. (2021). The cultivation of *Lactarius* with edible mushrooms. *Italian Journal of Mycology*, 50, 63–77.
<https://doi.org/10.6092/issn.2531-7342/12908>
- Whittaker, R. H. (1969). New Concepts of Kingdoms of Organisms: Evolutionary relations are better represented by new classifications than by the traditional two kingdoms. *Science*, 163(3863), 150–160.
<https://doi.org/10.1126/science.163.3863.150>
- Wong, K. H., Sabaratnam, V., Abdullah, N., Kuppusamy, U. R., & Naidu, M. (2009). Effects of cultivation techniques and processing on antimicrobial and antioxidant activities of *Herichium erinaceus* (Bull.: Fr.) Pers. extracts. *Food Technology and Biotechnology*, 47(1), 47–55.
- Woodward, S., & Boddy, L. (2008). Chapter 7 Interactions between saprotrophic fungi. In *British Mycological Society Symposia Series* (Vol. 28, pp. 125–141). Elsevier. [https://doi.org/10.1016/S0275-0287\(08\)80009-4](https://doi.org/10.1016/S0275-0287(08)80009-4)
- Wu, S., Zorn, H., Krings, U., & Berger, R. G. (2007). Volatiles from submerged and surface-cultured beefsteak fungus, *Fistulina hepatica*. *Flavour and Fragrance Journal*, 22(1), 53–60. <https://doi.org/10.1002/ffj.1758>
- Yamanaka, T., Yamada, A., & Furukawa, H. (2020). Advances in the cultivation of the highly-prized ectomycorrhizal mushroom *Tricholoma matsutake*. *Mycoscience*, 61(2), 49–57.
<https://doi.org/10.1016/j.myc.2020.01.001>
- Yılmaz, H., & Zencirci, N. (2015). *Batı Karadeniz Bölgesi Makromantarlarına Etnomikolojik Bir Bakış: Tanımlamadan Pazarlamaya*.
- Zakrzaska, A., Krasińska, N., & Kitlas, P. (2024). Effects of *Phallus Impudicus* Extract for Accelerating Hard-Healing Wounds in Diabetes-Induced Rats. *Acta Poloniae Pharmaceutica*, 81(6).
<https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=0016837&AN=184609152&h=sxKpGNFRhWo8aKzoBkzjA%2BKv%2B3pOp6NvrEucPyjWgf9SOArI RJShSzcw%2FsaUo7KkRs9Nka%2BZXyknbnvgAI1lg%3D%3D&crl=c>
- Zambonelli, A., Iotti, M., & Hall, I. (2015). Current status of truffle cultivation: Recent results and future perspect. *Micologia Italiana*, 31-40 Pages. <https://doi.org/10.6092/ISSN.2465-311X/5593>
- Zhang, Y., Peng, L., Wang, S., Yao, J., Feng, L., Yang, C., Wang, N., Lin, Y., Jiao, L., & Peng, R. (2025). *Lycoperdon perlatum* from a coniferous forest forms an ectomycorrhizal relation with and increases drought resistance of *Populus × canadensis* ‘Zhongliao 1.’ *Symbiosis*, 95(1), 111–123.
<https://doi.org/10.1007/s13199-025-01035-4>
- Zhou, X. (2017). Cultivation of *Ganoderma lucidum*. In C. Z. Diego & A. Pardo-Giménez (Eds.), *Edible and Medicinal Mushrooms* (1st ed., pp. 385–413). Wiley. <https://doi.org/10.1002/9781119149446.ch18>
- Zitte, L. F., Awi-Waadu, G. D. B., & John, A. U. (2012). Effect of oyster mushroom (*Pleurotus ostreatus*)

mycelia on petroleum hydrocarbon contaminated substrate. *Journal of Agriculture and Social Research (JASR)*, 12(2), Article 2.

Zotti, M., Persiani, A., Ambrosio, E., Vizzini, A., Venturella, G., Donnini, D., Angelini, P., Piazza, S., M, P., Lunghini, D., Venanzoni, R., Polemis, E., Granito, V., Maggi, O., Gargano, M., & Zervakis, G. (2013). Macrofungi as ecosystem resources: Conservation versus exploitation. *Plant Biosystems*, 147, 1–7.
<https://doi.org/10.1080/11263504.2012.753133>

Figures

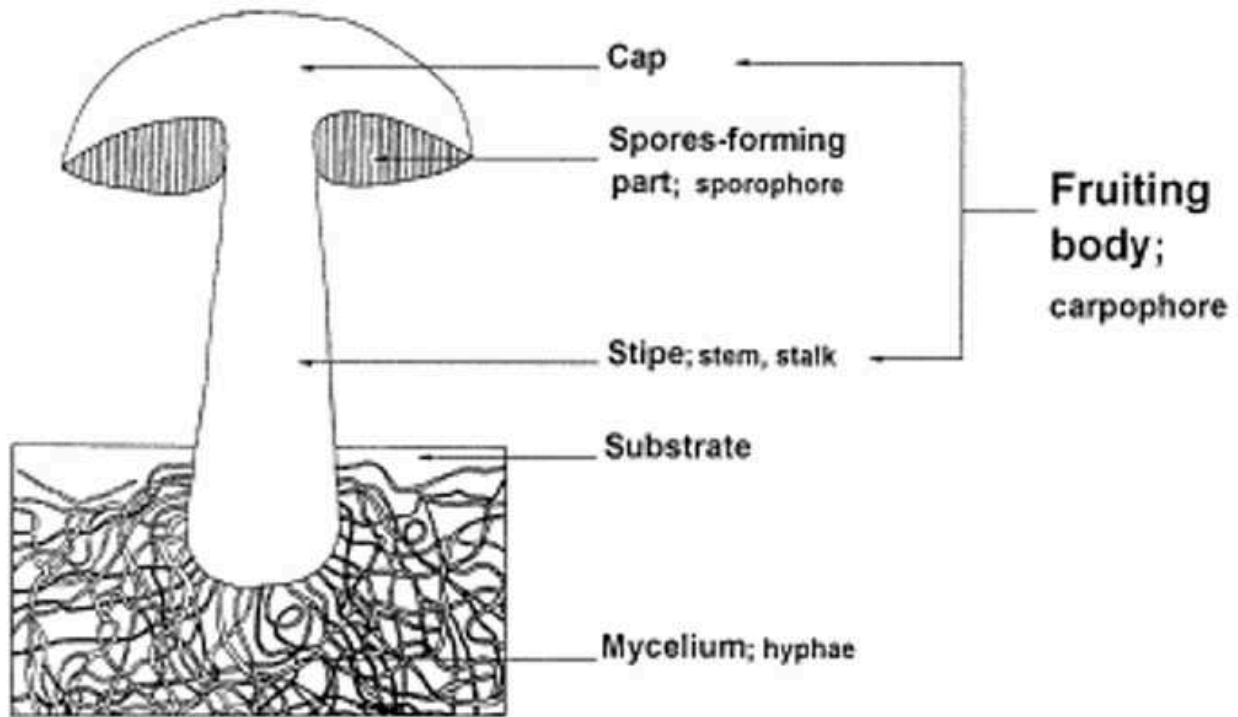


Figure 1

Figure 1.1. A visual of the above and below-ground parts of the mushroom and mycological terms for the parts of a cap mushroom (Kalac, 2001).



Figure 2

Figure 1.2. Cultivated *Lentinula edodes* (Shiitake) on a log, an example for outdoor cultivation methods (*Organic Shiitake Mushroom Plug Spawn*, n.d.).

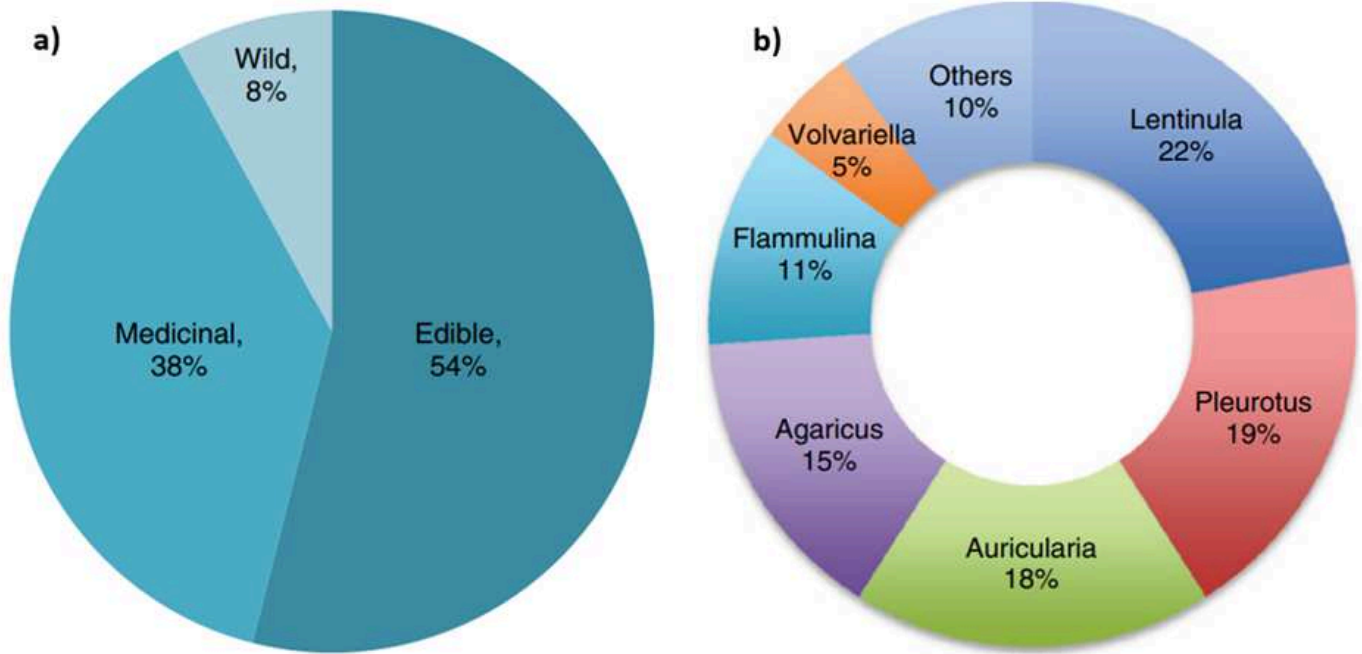


Figure 3

Figure 1.3. Pie charts showing: (a) global mushroom industry distribution, and (b) global edible mushroom production shares in 2013 (Royse et al., 2017; Stabnikova et al., 2024).



Figure 4

Figure 2.1. *Pleurotus* (oyster) mushrooms in different colors: a) *P. ostreatus* (grey oyster mushroom), b) *P. citrinopileatus* (golden oyster mushroom), c) *P. djamor* (pink oyster mushroom) (Tiupova et al., 2025).

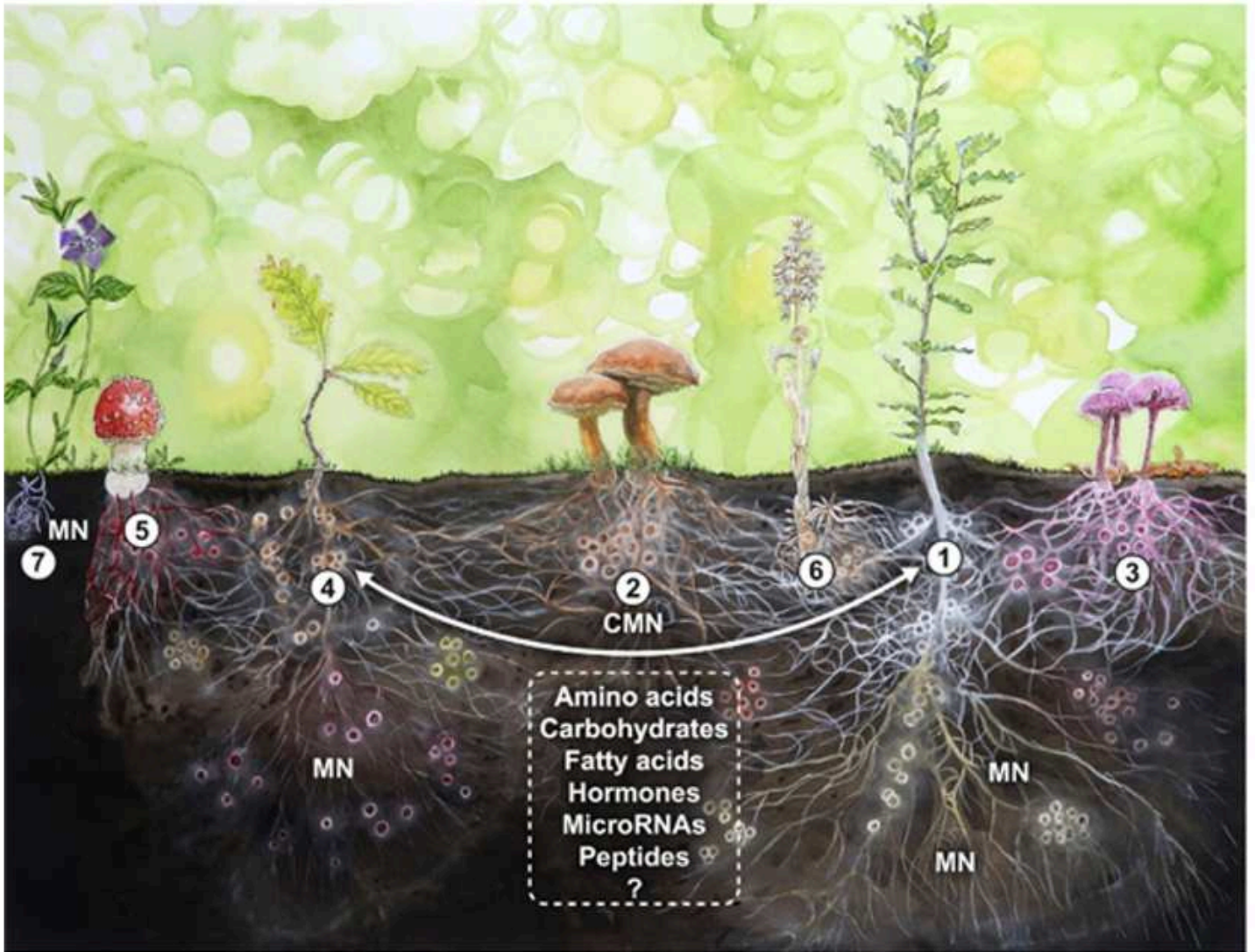


Figure 5

Figure 2.2.Representation of mycorrhizal networks (MN) formed by underground associations in a forest presumed to be dominated by oak species associated with different types of mycorrhizal fungi (Martin & van der Heijden, 2024).

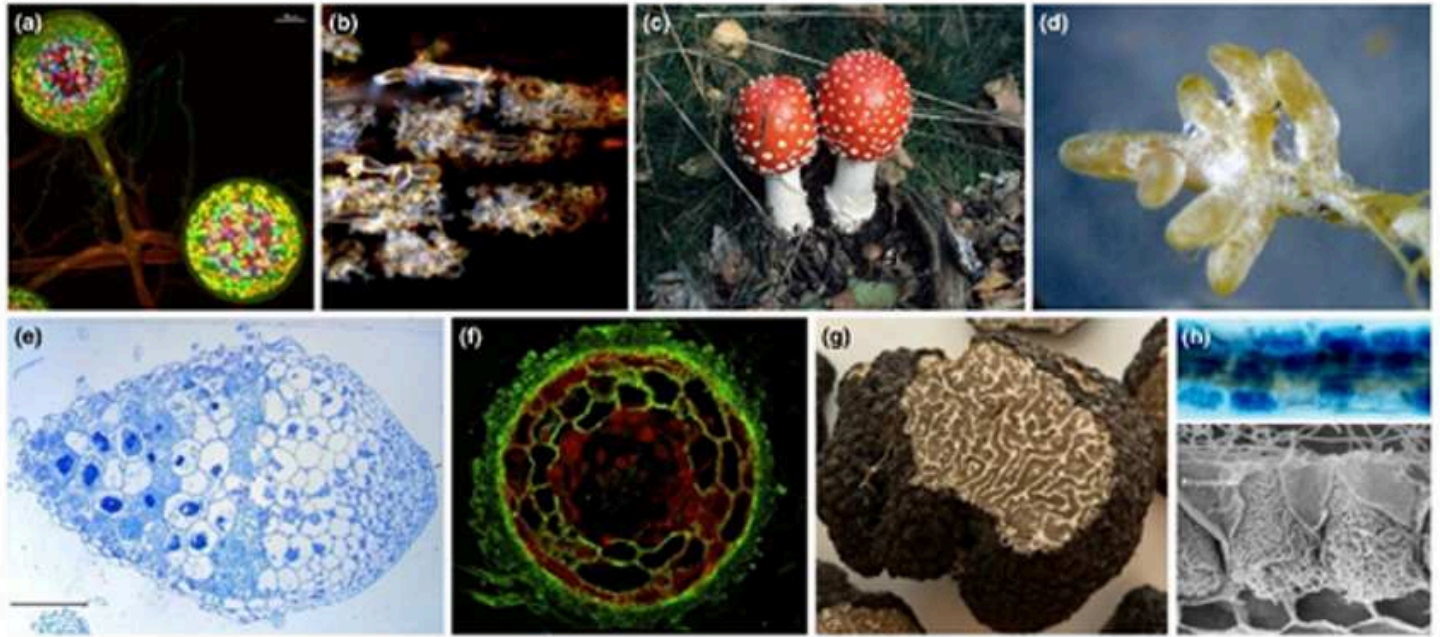


Figure 6

Figure 2.3. Typical structures of various types of mycorrhizal symbiosis (Martin & van der Heijden, 2024).



Figure 7

Figure 2.4. Mycorrhizae of *Lactarius deliciosus*. a) An aged mycorrhizal root section displaying white fungal hyphae attached to the orange mantle of *L. deliciosus* b) Extensively mycorrhized plants cultivated at Truffles and Mushrooms (Consulting) Limited facilities c) A single mycorrhizal root tip d) A solitary root tip showing hyphal growth toward the apex from the pigmented mantle e) Additional mycorrhized plant specimen from the same facility (Wang et al., 2021).



Figure 8

Figure 2.5. An example of an agroforestry integration method: an established truffle orchard (*A Beginner's Guide to Growing Truffles, Blog: Field & Forest Products, n.d.*).



Figure 9

Figure 2.6. Illustration of Beefsteak fungus, *Fistulina hepatica*, by Carlo Vittadini (1835).

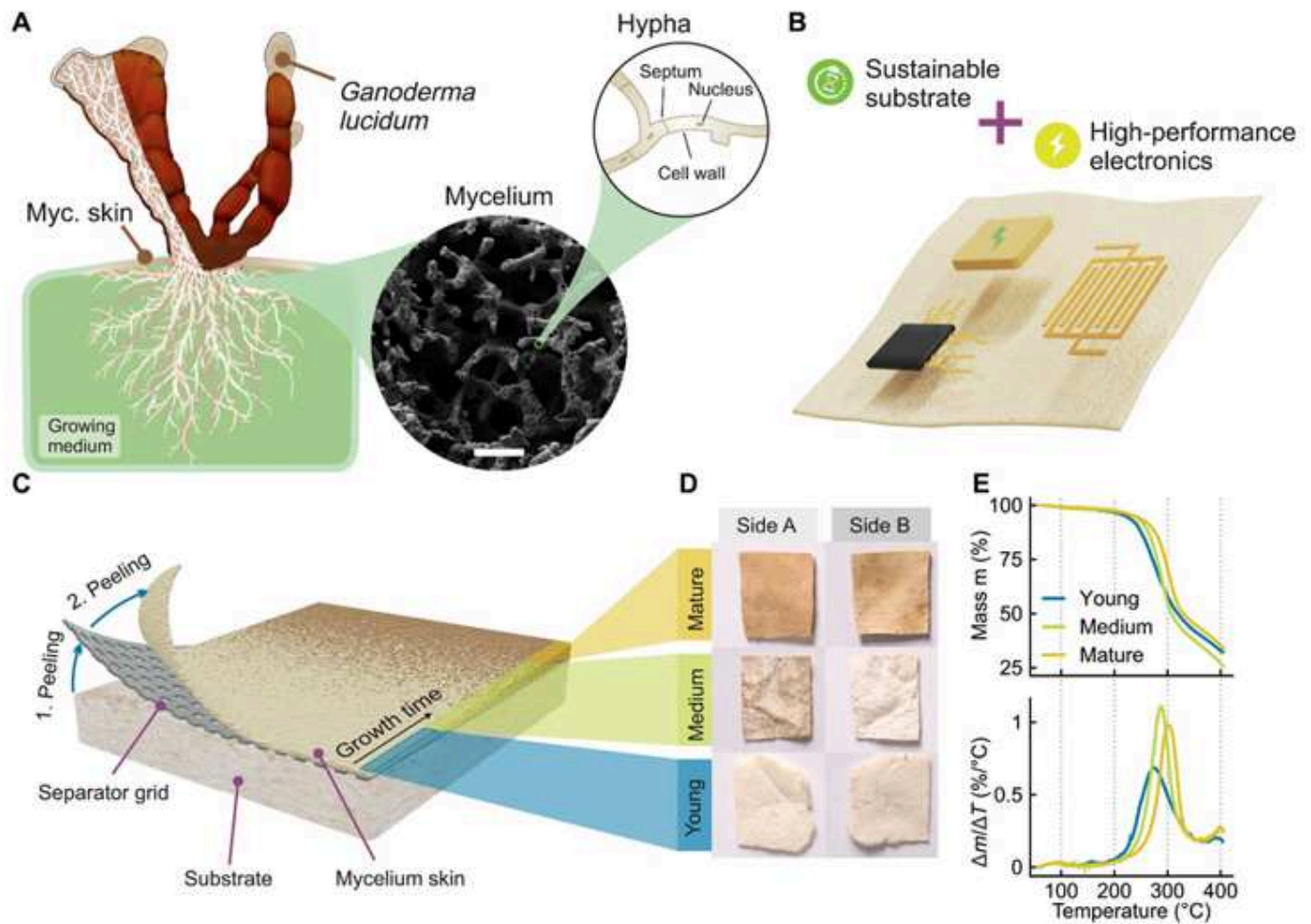


Figure 10

Figure 3.1. Morphological features of *Ganoderma lucidum* and its material structure applicable to sustainable electronic technologies (Danninger et al., 2022).