Mushroom Cultivation Systems: Exploring Antimicrobial and Prebiotic Benefits

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MUSHROOM farming is the practice of growing and cultivating various species of mushrooms for food, medicinal, or industrial purposes. It involves creating the ideal environment and conditions for the mushrooms to grow and thrive, such as providing a substrate (a nutrient-rich material on which mushrooms grow), controlling temperature and humidity, and ensuring proper ventilation and lighting. Several innovative applications of mushrooms can be noticed in their farming and cultivation. These applications mainly focus on the medicinal and prebiotic attributes, besides their role in producing food and energy. This review is an attempt to highlight the cultivation of mushrooms and their requirements under different kinds of farming. These farming types may include mushroom-worm system, mushroom-bee farming, smart mushroom farming, forest-mushrooms farming, urban mushroom farming, and mushroom-livestock farming. In this study the condition of cultivation of several mushroom species and their edibility is included. Edible/medicinal mushrooms are well-known for their high content of many beneficial bioactive ingredients for human health such as antioxidants, ergosterols, lectins, phenolics/polyphenolics, polysaccharides, and terpenoids. These bioactives of mushrooms have the potential capability to treat and/or prevent several chronic diseases. The medicinal and prebiotic attributes of mushrooms still need more investigation, and this topic of “mushrooms in medicine” still has several open questions needed to be answered in the future.

Keywords: Mushroom-worm farming, Mushroom-bee farming, Smart mushroom farming, Forest-mushrooms farming, Urban mushroom farming, Mushroom-livestock farming.

1. Introduction
Cultivation of mushrooms is thought to be back over four thousand years of many edible and medicinal mushroom species by the ancient Egyptians, Japan and China (Cotter 2014). The cultivation of mushrooms needs an understanding of all development stages, which include the release of the spores (sporulation), their germination on a suitable
growing media, colonization as much territory as possible to build up a competitive biomass, complete colonization and primordia formation, and mature mushrooms for producing spores, and the cycle starts again (Cotter 2014). Several reports have been published on mushroom cultivation from different points of view such as the cultivation of mushrooms as a sustainable integrated agriculture model (Ye et al. 2023), for mycoremediation (Sahithya et al. 2022), supporting selenium in removing mercury from soil (Pereira de Oliveira et al. 2023), for biofuel production (Leong et al. 2023), and biosynthesis of nanoparticles for removing organic pollutants (Chauhan et al. 2023).

Mushroom farming could be found in several types including mushrooms for healthy foods (Bell et al. 2022), mushroom-worn farming (Yang et al. 2023), mushroom-bee farming system, smart mushroom farming (Rahman et al. 2022), forest-mushrooms farming (Copena et al. 2022), urban mushroom farming (Dorr et al. 2021), and mushroom-livestock farming (Wang et al. 2022).

Edible mushrooms have unique nutritional attributes that allow use as a source of protein meat analog compared with animal meat and plant-based meat analogs (Wang and Zhao 2023). Many recent studies confirmed the bright side of mushrooms as a future generation healthy food (e.g., Okuda 2022; Bell et al. 2022). Many applications of biotechnology in mushroom farming, which focuses on traditional cultivation include mining biosynthetic gene clusters, precision breeding, developing mushroom chassis cells, and constructing cell factories for high value-added products (Zou et al. 2023). Several mushrooms have a great potential source of active metabolites and medicines (Bhambri et al. 2022).

Therefore, several therapeutic applications of mushroom including edible and medicinal ones were reported (Chugh et al. 2022; Ahmad et al. 2023), which may include more than 130 medicinal activities such as antioxidant, antitumor, cardioprotective and antiviral actions, immunomodulation, and radical scavenging (Chugh et al. 2022).

Therefore, this review presents an overview of the mushrooms and their cultivation and different antimicrobial and prebiotic properties, in addition, different mushroom farming types will be highlighted.

2. Mushroom farming requirements

The cultivation of mushrooms is an important industry, which can gain a potential income. This industry can be carried out indoors or outdoors (in the open field or forests). Due to its importance, mushrooms have a promising strategy in the Nano-Food Lab (Debrecen university), which started several years ago (Figure 1). This plan was successfully translated into many publications and many patents in progress including many research areas such as cultivating edible mushroom in polluted soils (El-Ramady et al. 2021), the green biotechnology of mushrooms (El-Ramady et al. 2022a), the nutritional and medicinal attributes of edible mushrooms (El-Ramady et al. 2022b), the sustainable production of food and energy (El-Ramady et al. 2022c), the sustainable soil nanomanagement (Elsakhawy et al. 2022), sustainable applications in soil science (Fawzy et al. 2022), and edible mushrooms with focus on Pleurotus spp. (Tőrő et al. 2022), and Lentinula spp. (Hajdú et al. 2022).

Pleurotus mushrooms are globally well-cultivated on a large scale, accounting for 27% of their global production (Raman et al. 2021). Several mushrooms can adapt their growing to a wide range of temperatures, at relatively high humidity and high CO₂ levels without requiring specific controlled environmental conditions (Raman et al. 2021). In general, there are seven steps for mushroom cultivation are presented in Figure 2, whereas Figure 3 includes some photos of mushroom farming (Pleurotus ostreatus). The main systems of mushroom cultivation could be the following:

I. Outdoor systems (e.g., logs, stumps, and wood chips), and

II. Indoor systems (e.g., bags under greenhouse conditions, bottles of king oyster, bags hung in a wall formation, horizontal shelf with bags, shelf cultivation of mushrooms, a-frame shelf with bags, tray cultivation of mushrooms, and sawdust blocks of mushrooms).

The main types of mushroom spawn include sawdust spawn, grain spawn, plug or dowel spawn, straw spawn, naturalized or wild spawn, and liquid spawn.
The substrate of cultivated mushrooms differs depending on the climate zone of the cultivation area and the system. For example, Cotter (2014) reported that the available substrate under temperate climate (16–29°C) may involve the following systems:

1- Logs and stumps (e.g., beefsteak, birch polypore, black poplar, cauliflower, and chicken of the woods),

2- Wood mulch or chips (e.g., brick top, king Stropharia, and parasol),

3- Composts and livestock waste (e.g., almond portabolla, and king Stropharia, parasol, shaggy mane, and composted livestock manure),

4- Agricultural waste, straw, plant debris (e.g., Elm oyster, king Stropharia, parasol, and shimeji),

5- Sawdust (e.g., black poplar, beefsteak, elm oyster, and hairy panus).

Fig. 1. List of activities of the Nano-Food Lab (Debrecen University, Hungary) in part (A), which includes many applications of mushrooms (part B).
The Seven Basic Stages of Mushroom Cultivation

1. **Preparation of media by making mushroom compost:** Growing medium or the substrate may be hardwood chips, manure-based compost, and hardwood logs and stumps, and sterilized media.

2. **Inoculation and finishing the compost:** Depending on the cultivation outdoor or in a factory, the substrate should inoculate and mix it into the media, and then filling the containers.

3. **The spawn run or spawning:** This period is called the spawn run or colonization period. Colonization of logs or bulk media.

4. **Complete colonization and casing:** A complete spawn run, and a few days/weeks before mushrooms appear.

5. **Initiation and pinning:** Primordia (colonized mycelium appear) enlarge and rupture from the bark on the logs, depending on the values of temperature, light, and watering or humidity.

6. **Maturation and harvesting:** The mushrooms are ready to pick, primordia enlarge and mature; harvest when growth slows or stops within 35-42 days (up to 60 d), and harvest continues for 150 days.

7. **The rest period:** Mycelia are in need of a well-deserved period of rest before the next flush after harvesting.

Fig. 2. The main steps in cultivation of mushrooms according to Cotter (2014).

*Pleurotus ostreatus* mycelium on different media (directly after vaccination; room temperature)
**Pleurotus ostreatus** mycelium on different media after 3 days from incubation stage at room temperature

The microscopic image of secondary metabolite products with orange ball appearance on oyster mycelium

The first harvest of *Pleurotus ostreatus* mushroom grown on corn husks based compost
The first harvest of fresh *Pleurotus ostreatus* mushroom as a bouquet grown on corn husks-based compost

Freeze-dried *Pleurotus ostreatus* mushrooms, which has been grown on corn husks-based compost

Fresh washed, sliced *Pleurotus ostreatus*

Fig. 3. Some main steps of oyster mushroom cultivation and harvesting from Nano Food Lab (Debrecen University, Hungary). All photos by Gréta Törös.

3. Mushroom farming types

The cultivation of mushrooms under certain conditions is called mushroom farming, and this activity could be performed with or without sharing other agricultural activities like forestry or livestock, the types of farming are presented in Figure (4). Generally, wild mushrooms can grow (up to 10,000 different types of mushrooms), can be classified into 4 categories: parasitic, saprotrophic, mycorrhizal, and endophytic. The consumed mushroom substrate can be used in producing low-carbon biofuel (Leong et al. 2022). Although mushrooms have so many uses, the potential for producing a healthy food is quite important. It is very
important to highlight the edibility of many mushrooms in this study as presented in Table 1, and they are classified into edible, inedible, toxic, and unknown. The edibility and more growing details besides English and scientific name of these groups of mushrooms are listed as well in Table 1.

Figure 4.
Mushroom farming systems including production of different farming types with focus on foods, livestock, vermicompost, etc.

Table 1. Some common mushrooms in the forestry system with its edibility (adapted from Yan 2023), and the scientific names according to https://www.gbif.org/species.

<table>
<thead>
<tr>
<th>English name</th>
<th>Scientific name</th>
<th>Edibility and forest growing details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coral Slime</td>
<td>Ceratiomyxafruticulosei. aurantiacaJaap, (1922)</td>
<td>Rotten wood, sometimes on dead leaves. Not Edible</td>
</tr>
<tr>
<td>Scrambled Egg Slime</td>
<td>FuligosepticaL. (F.H.Wigg., (1780)</td>
<td>Deciduous forests, on rotten wood, bark, or dead leaves. Not Edible</td>
</tr>
<tr>
<td>The Hidden Forest</td>
<td>Stemonitisaxifera(Bull.) T.Macbr., (1899)</td>
<td>Rotten Wood. Not Edible</td>
</tr>
<tr>
<td>Wolf's Milk Slime</td>
<td>Lycogalaepidendrum(L.) Fr., (1829)</td>
<td>Dead/Rotten wood. Not Edible</td>
</tr>
<tr>
<td>Raspberry Slime Mold</td>
<td>Tubiferaferruginosa(Batsch) J.F.Gmel., (1792)</td>
<td>Dead wood, dead leaves, or humus. Not Edible</td>
</tr>
<tr>
<td>Canadian Round-headed Cordyceps</td>
<td>CordycepscanadensisEllis&amp;Everh. (1898)</td>
<td>In humus under pines and deciduous trees. Latches on underground truffles. Not Edible</td>
</tr>
<tr>
<td>Adder's Tongue</td>
<td>Cordycesphingolossoides(J.F.Gmel.) Link (1818)</td>
<td>Found in humus of deciduous and mixed forests (birch), latches on to underground truffles, Not Edible</td>
</tr>
<tr>
<td>Black Knot of Cherry</td>
<td>DibotryonmorrhosumSchwein. Theiss.</td>
<td>Latches on to cherry trees such as</td>
</tr>
</tbody>
</table>
Agassiz's Lachnella  
*Lachnella agassizii* (Berk. & M. A. Curtis) Dennis (1962)  
In dense colonies on dead conifer bark, especially fir. Not edible.

Hairy Earth Tongue  
*Trichoglossum hirsutum* (Pers.) Boud. (1907)  
On humus or rotten wood. Not edible.

Dead Man's Fingers  
*Xylariapolymorpha* (Pers.) Grev. (1824)  
On dead branches, trunks, or logs. Even on live trees, especially on deciduous trees such as beech. Not edible.

Black Witch's Butter  
*Exidiaglandulosa* (Bull.) Fr. (1822)  
On dead branches from deciduous trees. Not edible.

White Coral Jelly Fungus  
*Tremellareticulata* (Berk.) Farl. (1908)  
On ground or on rotten wood or leaves. Especially in maple/oak forests. Not edible.

Perennial Polypore  
*Coltriciaperennis* (L.) Murrill (1903)  
On the ground in disturbed forests such as clear cuts or wildfire mainly in coniferous forests with birch and aspen. Not Edible.

Woolyvelvet polypore or Velvet Rosette  
*Onniatomentosa* (Fr.) P.Karst. (1889)  
On buried roots in coniferous forests. Not Edible.

Winter Polypore  
*Polyporus brumalis* (Pers.) Fr. (1818)  
On dead wood, especially birch wood. Not edible.

Variegated Polypore  
*Polyporus varius* (Pers.) Fr. (1821)  
On dead wood in deciduous forests. Not Edible.

Reddish Brown Crust  
*Hymenochaetae cinnabarinus* (Jacq.) P.Karst. (1881)  
On dead branches, mostly on conifers. Not Edible.

Red-belted Polypore/Red-Banded Polypore  
*Fomitopsis spinicola* (Sw.) P. Karst. (1881)  
On trunks of living or dead deciduous trees, such as birch. Not edible.

Artist's Conk  
*Ganoderma applanatum* (Pers.) Pat. (1887)  
On trunks of dead deciduous trees. Not edible.

Resinous Polypore  
*Ischnoderma resinosum* (Schrad.) P. Karst. (1879)  
On trunks of dead deciduous trees. Not edible.

Scaly Polypore  
*Polyporus squamosus* (Huds.) Quélet (1886)  
On trunks and logs of wounded deciduous trees. Not Edible.

False Timber Polypore  
*Phellinus cincterus* Niemelä (1881)  
On stumps, mostly of birch trees. Not edible.

Birch Polypore  
*Piptoporus betulinus* (Bull.) P. Karst. (1881)  
On dead birch trees. Not edible.

Turkey Tail Polypore  
*Trametes versicolor* (L.) Lloyd (1921)  
On stumps, trunks, logs, or branches of deciduous trees. Not edible, but Medicinal.

Cinnabar-red Polypore  
*Pycnoporus cinnabarinus* (Jacq.) P. Karst. (1881)  
On stumps, logs, or trunks of deciduous trees, commonly on cherry. Not edible.

Parchment Bracket or Violet-toothed polypore  
*Trichaptum biforme* (Fr.) Ryvarden (1972)  
On stumps, trunks, and logs of deciduous trees, sometimes covering the whole surface.
MUSHROOM CULTIVATION SYSTEMS: EXPLORING ANTIMICROBIAL AND PREBIOTIC BENEFITS


Northern Tooth: *Clamadon septentrionalis* (Fr.) P. Karst. (1881) - Not edible. On trunks of dead or living deciduous trees such as elm and maple. Not edible.

Fragrant Hydnum: *Hydnellumsuveoleon* (Scop.) P. Karst. (1879) - On mossy forest floor, lichen or needle covered soil. Not edible.


Luminescent Panellus: *Panellus stypticus* (Bull.) P. Karst. (1879) - In bunches, on rotten wood of deciduous forests. Not edible.

Orange Mock Oyster: *Phylloptopsis nidulans* (Pers.) Singer (1936) - In bunches, on dead wood of coniferous and deciduous forests. Not edible.

Pinwheel Marasmius: *Marasmius rotula* (Scop.) Fr. (1838) - In bunches on rotten wood, or on dead leaf litter, or within stacks of twigs in deciduous forests. Not edible.


Wrinkled Mycena: *Mycenagalericulata* (Scop.) Gray (1821) - In bunches on rotten wood of deciduous trees. Not edible.


Fuzzy Foot: *Xeromphalinacampanella* (Batsch) Kühner & Maire (1953) - In dense clusters on stumps, and trunks of rotten coniferous trees. Not edible.

Scaly Stropharia: *Strophariasquamosa* var. thrausta (Kalchbr.) Massée - On buried wood, in forests or fields. Not Edible.


False Morel: *Giromitraesculenta* (Pers. ex Pers.) Fr. (1849) - Open, sandy soils, in coniferous forests, particularly white pine, and mixed forests. Edible for some, but not recommended.


Common Jelly Baby: *Leotialubrica* - In dense colonies on rotten wood/ directly on the ground. Edible, but glutinous.

Black Morel: *Morchellaelata* Pers. Fr. (1822) - Deciduous forests, especially under poplar, but also in mixed forests. Edible, tasty, but better blanch them first.

Yellow Morel: *Morchellaesculenta* (L.) Pers. (1801) - Deciduous forests, especially under elms, and poplars. Edible, one of the tastiest, but better blanch them first.

Irregular Mitrula or Irregular Earth Tongue: *Neolectairregularis* (Peck) Korf & J.K. Rogers (1971) - On moss, or forest litter such as needles, in coniferous or mixed forests. Edible.

Bay Peziza or bay cup: *Pezizabadia* Pers. (1800) - In deciduous or mixed forests, often found on sandy soil. Edible.

Scarlet Cup: *Sarcoscyphaaustriaca* (Beck ex Sacc.) Boud. (1907) - On the soil, in burrowed wood, in deciduous forests such as maple forests. Edible.


Tree Ear: *Auriculariaauricula-judae* (Bull.) Quél. (1886) - On dead wood, especially on conifers like fir and spruce. Edible.

Toothed Jelly Fungus: *Pseudeohydnumgelatinosum* (Scop.) P. Karst. (1868) - On rotten wood in coniferous forests. Edible, but not particularly tasty.

Fake Coral Fungus: *Tremellodendron pallidum* Burt. (1915) - On ground in deciduous or mixed forests. Edible.
<table>
<thead>
<tr>
<th>Fungus Name</th>
<th>Scientific Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apricot Jelly Fungus</td>
<td><em>Tremiscushelvelloides</em> (DC.) Donk (1958)</td>
<td>On ground, or rotten wood in coniferous or mixed forests. Edible, but more decorative than tasty.</td>
</tr>
<tr>
<td>Sheep Polypore</td>
<td><em>Albatrellusovinus</em> (Schaeff.) Kotl. &amp; Pouzar (1957)</td>
<td>Under fir or spruce forests. Edible, quite tasty.</td>
</tr>
<tr>
<td>Chaga</td>
<td><em>Inonotus obliquus</em> (Fr.) Pilát (1942)</td>
<td>Latches on exclusively on birch trees. Highly medicinal, can be used as coffee alternative. Edible.</td>
</tr>
<tr>
<td>Chicken of the Woods</td>
<td><em>Laetiporussulphureus</em> (Bull.) Murrill (1920)</td>
<td>On trunks and logs of deciduous trees. Edible, but with variety of results.</td>
</tr>
<tr>
<td>Comb Tooth</td>
<td><em>Hericiumcoralloides</em> (Scop.) Pers. (1794)</td>
<td>On trunk of dead or living deciduous trees. Edible.</td>
</tr>
<tr>
<td>Sweet Tooth (Wood Hedgehog)</td>
<td><em>Hydnumrepandum</em> L. (1753)</td>
<td>In mixed, deciduous or coniferous forests. Edible, very tasty.</td>
</tr>
<tr>
<td>Fairy Fingers</td>
<td><em>Clavariaphragilis</em> Holmsk. (1790)</td>
<td>In dense groups on the ground within herbs, and humus, in deciduous forests. Edible.</td>
</tr>
<tr>
<td>Purple fairy club</td>
<td><em>Clavariapurpurea</em> (Fr.) Dentinger &amp; D.J. McLaughlin (2007)</td>
<td>In colonies on the ground, within herbs, or humus, in coniferous forests. Edible.</td>
</tr>
<tr>
<td>White coral fungus or the crested coral fungus</td>
<td><em>Clavulinacristata</em> (Holmsk.) J. Schröd. (1888)</td>
<td>On the ground within moss, and humus, in coniferous or mixed forests. Edible.</td>
</tr>
<tr>
<td>Spindle-shaped Clavaria</td>
<td><em>Clavulinosfusiformis</em> (Sowerby) Corner (1950)</td>
<td>In dense clusters within herbs, or on bare soil, within coniferous or mixed forests. Edible.</td>
</tr>
<tr>
<td>Chanterelle</td>
<td><em>Cantharelluscibarius</em> Fr. (1821)</td>
<td>In coniferous, and mixed forests, and more rarely in deciduous forests. Edible, tasty.</td>
</tr>
<tr>
<td>Appalachian Chanterelle</td>
<td><em>Cantharellusappalachiensis</em> R.H. Petersen (1971)</td>
<td>In deciduous forests, often under oaks, and beech. Edible, tasty.</td>
</tr>
<tr>
<td>Cinnabar Chanterelle</td>
<td><em>Cantharelluscinabarinus</em> (Schwein.) Schwein. (1832)</td>
<td>On the forest floor, within moss, or along paths, in deciduous forests, often under oaks. Edible, tasty.</td>
</tr>
<tr>
<td>Black Trumpet</td>
<td><em>Craterellusfallax</em> A.H. Sm. (1968)</td>
<td>In deciduous, and mixed forests. Edible, tasty.</td>
</tr>
<tr>
<td>Trumpet Chanterelle or Yellowfoot</td>
<td><em>Craterellustubaeformis</em> (Fr.) Quél. (1888)</td>
<td>In coniferous, or mixed forests. In moist areas such as peat bogs, in sphagnum moss. Edible, tasty.</td>
</tr>
<tr>
<td>Oyster Mushroom</td>
<td><em>Pleurotusostreatus</em> (Jacq. ex Fr.) P. Kumm. (1871)</td>
<td>In bunches, on living or dead deciduous trees, especially on maple, oak, beech, and birch. Edible, tasty.</td>
</tr>
<tr>
<td>Summer or pale Oyster</td>
<td><em>Pleurotusulmonarius</em> (Fr.) Quél. (1872)</td>
<td>In bunches, on living or dead deciduous trees, such as maple, beech, oaks, and birch. Edible, tasty.</td>
</tr>
<tr>
<td>Late Fall Oyster</td>
<td><em>Sarcomyxaserotina</em> (Pers.) P. Karst. (1891)</td>
<td>In bunches, on dead deciduous trees. Edible, tasty.</td>
</tr>
<tr>
<td>Golden Waxy Cap</td>
<td><em>Hygrocybechlorophana</em> (Fr.) Wünsche (1877)</td>
<td>In coniferous, mixed, or deciduous forests. Edible, but not recommended.</td>
</tr>
<tr>
<td>Chanterelle or Goblet Waxy Cap</td>
<td><em>Hygrocybechaneharella</em> (Schwein.) Murrill (1911)</td>
<td>On extremely rotten wood covered in moss, and on sphagnum moss within humid peat bogs. Edible</td>
</tr>
<tr>
<td>Scarlet Waxy Cap</td>
<td><em>Hygrocybecoccinea</em> (Schaeff.) P. Kumm. (1871)</td>
<td>On the forest floor in deciduous, and mixed forests. Edible.</td>
</tr>
<tr>
<td>Witch's Hat or Blackening Waxcap</td>
<td><em>Hygrocybeconica</em> (Schaeff.) P. Kumm. (1871)</td>
<td>On the forest floor in deciduous, mixed, or coniferous forests; or in open meadows, and groves. Edible, but not recommended.</td>
</tr>
<tr>
<td>Mushroom Name</td>
<td>Scientific Name</td>
<td>Location Notes</td>
</tr>
<tr>
<td>----------------------------</td>
<td>---------------------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Dark Honey Fungus</td>
<td><em>Armillaria ostoyae</em> (Romagnesi) Herink, (1973)</td>
<td>Found in tree stumps, roots, and dead trunks in deciduous or coniferous forests. Edible.</td>
</tr>
<tr>
<td>Grayling or the Humpback</td>
<td><em>Cantharellulaumbonata</em> (J.F.Gmel.) Singer, (1936)</td>
<td>Found on mossy forest floors, in meadows, or groves of coniferous or mixed forests. Edible.</td>
</tr>
<tr>
<td>Anis-scented Clitocybe</td>
<td><em>Clitocybe odora</em> (Bull.) P. Kumm. (1871)</td>
<td>Edible, aromatic. On leaf litter in deciduous or mixed forests.</td>
</tr>
<tr>
<td>False Chanterelle</td>
<td><em>Hygrophoropsis aurantiaca</em> (Wulfen) Maire ex Martin-Sans, (1921)</td>
<td>In little groups on the group or on rotten wood in mixed or coniferous forests. Edible, tasty.</td>
</tr>
<tr>
<td>Iris-scented Lepista</td>
<td><em>Lepista aurina</em> (Fr.) H.E. Bigelow, (1959)</td>
<td>Edible. In deciduous, mixed, or coniferous forests, within herbs on open ground. Edible, may cause gastrointestinal problems.</td>
</tr>
<tr>
<td>Fetid Tricholoma or</td>
<td><em>Tricholoma focale</em> (Fr.) Ricken, (1914)</td>
<td>Edible. In coniferous forests, as well as deciduous, and mixed. Edible, but not great.</td>
</tr>
<tr>
<td>booted knight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canary Trich or Yellow</td>
<td><em>Tricholoma equestre</em> (L.) P. Kumm., (1871)</td>
<td>Edible. In coniferous or mixed forests, often under pine trees. Edible, but eat in small quantity.</td>
</tr>
<tr>
<td>Knight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shingled Trich</td>
<td><em>Tricholoma imbricatum</em> (Fr.) P. Kumm., (1871)</td>
<td>Edible. In bunches, within coniferous, or mixed forests, especially near jackpine. Edible, but eat in small quantities.</td>
</tr>
<tr>
<td>Sticky Gray Trich or</td>
<td><em>Tricholoma portentosum</em> (Fr.) Quél., (1873)</td>
<td>Edible. In coniferous forests, but sometimes under beech trees. Edible, tasty.</td>
</tr>
<tr>
<td>Coalman</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soapy Trich</td>
<td><em>Tricholoma asaponaceum</em> (Fr.) P. Kumm., (1871)</td>
<td>Edible. In coniferous forests, often under spruce, but also in deciduous or mixed forests. Edible, but not recommended.</td>
</tr>
<tr>
<td>Brownish-yellow Tricholoma</td>
<td><em>Tricholoma transmutans</em> (Peck) Sacc., (1887)</td>
<td>Edible. In coniferous, or mixed forests, often under birch trees, or growing alongside moss. Edible, but mediocre.</td>
</tr>
<tr>
<td>Fibril Trich</td>
<td><em>Tricholoma virgatum</em> (Fr.) P. Kumm., (1871)</td>
<td>Edible. In coniferous, or mixed forests, often growing alongside moss. Edible (mediocre)</td>
</tr>
</tbody>
</table>

(3) Group of toxic mushrooms

<table>
<thead>
<tr>
<th>Mushroom Name</th>
<th>Scientific Name</th>
<th>Location Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastern American Jack</td>
<td><em>Omphalotus illudens</em> (Schwein.)</td>
<td>In bunches on trunks, or roots of oak trees. Extremely toxic.</td>
</tr>
<tr>
<td>O' Lantern</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red-brown</td>
<td><em>Tricholoma pessundatum</em> (Fr.) Quél. (1872)</td>
<td>In coniferous forests. Not edible, toxic.</td>
</tr>
<tr>
<td>Trichor Tacked Knight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red-gilled Cort or Surprie Webcap</td>
<td><em>Cortinarius semisanguineus</em> (Fr.) Gillet, (1876)</td>
<td>In coniferous, mixed, or oak forests. Not edible, dangerous.</td>
</tr>
<tr>
<td>Poison Pie</td>
<td><em>Hebeloma acrastuliforme</em> (Bull. ex)</td>
<td>In deciduous, or coniferous forests. Also on</td>
</tr>
</tbody>
</table>

### 4. Mushroom antimicrobial and prebiotic attributes

No doubt that edible mushrooms can be considered an important source for healthy food for the next generation. These edible mushrooms have a great nutritional value due to their rich in ash (7-17%), dietary fiber (16–20%), proteins (30-48%), fat (1–4%), carbohydrate (12.5–40%), minerals, and vitamins like B₁, B₂, B₁₂, C, D, and E (Raman et al. 2021; Bhambari et al. 2022), as well as other bioactive components including alkaloids, lactones, polyphenolic compounds, polysaccharides, sesquiterpenes, sterols, and terpenoids (El-Ramady et al. 2022b). These bioactive ingredients are considered health-promoting supplements when extracted from edible mushrooms and applied to human foods. Several human diseases have been treated using edible mushroom extracts due to their biological impacts particularly antidiabetic, anticancer, hepatoprotective, antiviral, antioxidant, immune-potentiating, and hypo-cholesterol impacts (Chugh et al. 2022). The health benefits of some common mushrooms were listed in Figure (5). Mushroom protein can be considered a novel protein alternative (Ayimbila and Keawsompong 2023). Concerning the prebiotic properties of mushrooms, they exhibited distinguished influence as prebiotic properties due to their high content of many prebiotic components (e.g., chitin, hemicellulose, β and α-glucans, mannan, xylans, galactans, and inulin) as reported by many studies (e.g., Jayachandran et al. 2017; Moumita and Das 2022; Zhang et al. 2022). The prebiotic action of mushrooms may express as a stimulator of the growth of gut microbiota, conferring health benefits to the host.

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Location</th>
<th>Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw-colored Fiber Head</td>
<td>Inocybeastra (Bull.) P. Kumm.</td>
<td>In deciduous, mixed, or coniferous forests.</td>
<td>Toxic.</td>
</tr>
<tr>
<td>or Split Fibrecap</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White Fiber Head</td>
<td>Inocybeastra (Bull.) P. Kumm.</td>
<td>On the ground in deciduous, mixed, or coniferous forests.</td>
<td>Toxic.</td>
</tr>
<tr>
<td>Marginate Galerina</td>
<td>Galeriniamarginalis (Batsch) Kühner (1935)</td>
<td>In bunches on trunk of rotten deciduous, and coniferous trees.</td>
<td>Toxic. DEADLY.</td>
</tr>
<tr>
<td>Laughing Mushroom or Yellow Gymnopilus</td>
<td>Gymnopilusflavus (Peck) Hesler (1969)</td>
<td>In dense bunches, on trunk and logs of dead deciduous, and coniferous trees. Not edible, contains hallucinogenic toxins.</td>
<td></td>
</tr>
<tr>
<td>Shaggy-stalked Lepiota</td>
<td>Leptiotaclepeolaria (Bull.) P.Kumm.</td>
<td>In coniferous or mixed forests.</td>
<td>Toxic.</td>
</tr>
<tr>
<td>Rosy Entoloma or Wood Pinkgill</td>
<td>Entolomamarhododolium (Fr.) P. Kumm.</td>
<td>On forest floors.</td>
<td>Toxic.</td>
</tr>
<tr>
<td>Lead Poisoner or Livid Pinkgill</td>
<td>Entolomaminutum (Bull.) P. Kumm.</td>
<td>On forest floors.</td>
<td>Highly Toxic.</td>
</tr>
<tr>
<td>Destroying Angel</td>
<td>Amanita virosa Bertill. (1866)</td>
<td>In mixed forests, especially under birch.</td>
<td>Toxic. Deadly.</td>
</tr>
<tr>
<td>Poison Paxillus</td>
<td>Paxillusinvolutus (Batsch) Fr. (1838)</td>
<td>On forest floors of coniferous, mixed or deciduous forests.</td>
<td>Toxic.</td>
</tr>
<tr>
<td>Common Scleroderma or common earthball</td>
<td>Scleroderma citrinum Pers. (1801)</td>
<td>Near stumps, rotten wood, in forests or open grounds.</td>
<td>Not edible, toxic.</td>
</tr>
</tbody>
</table>

#### (4) Group of unknown edibility mushrooms

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Location</th>
<th>Toxicity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smeared Cort</td>
<td>Cortinariusmultiformis Fr. (1838)</td>
<td>In deciduous, coniferous, or mixed forests.</td>
<td>Unknown.</td>
</tr>
<tr>
<td>Variable Cort</td>
<td>Cortinariusstrigatus (Fr.) Fr. (1838)</td>
<td>In mixed, or coniferous forests.</td>
<td>Unknown.</td>
</tr>
<tr>
<td>Pungeant Cort or Gassy Webcap</td>
<td>Cortinariusviolaceus (L.) Gray (1821)</td>
<td>In mixed, or coniferous forests.</td>
<td>Unknown.</td>
</tr>
<tr>
<td>Violet Cort or Violet Webcap</td>
<td>Agrocybeaegeriana (Peck) Singer (1907)</td>
<td>In mixed, or coniferous forests, often near birch trees.</td>
<td>Unknown.</td>
</tr>
<tr>
<td>Dark-centered Lactarius or Eye Spot Milky</td>
<td>Lactariusviolaceus (Fr.) Fr. (1838)</td>
<td>In small bunches on humid soils, along moss in coniferous or mixed forests.</td>
<td>Unknown.</td>
</tr>
<tr>
<td>Common Lactarius or Tacked Milkcap</td>
<td>Not edible, toxic.</td>
<td>In coniferous forests.</td>
<td>Unknown.</td>
</tr>
</tbody>
</table>
Horse Mushroom
*Agaricus arvensis* L. (Schaeff.) 1774
Uses: cancer, cardiovascular disease, immune diseases, lower back pain

Champignon, Button Mushroom, Portobello
*Agaricus bisporus* L. (J.E.Lange) Imbach (1946)
Cancer, antioxidant, antimicrobial, cognitive function, cardiovascular disease, age, gut health

Field Mushroom
*Agaricus campestris* L.
Diabetes, cancer, antimicrobial, antioxidant, lung cancer, fatigue

Almond Mushroom
*Agaricus subrufescens* L. Peck (1893)
Cancer, allergies, diabetes, dermatitis, hepatitis, infections, tumors, inflammation, high cholesterol

Jelly Ear Fungus
*Auricularia auricula-judae* (Bull.) Quél. (1886)
Inflammation, sore throat, fever, healthy blood, antioxidant, tumor, anticoagulant

Turkey Tail
*Coriolus versicolor* L. (Quél.) (1886)
Immune System, cancer, diabetes
Enokitake, Enoki
*Flammulina velutipes* (Curtis) Singer (1951)
Cancer, immune system, antimicrobial, antioxidant, neurodegenerative diseases, high cholesterol, inflammation, aging

Birch Polypore
*Fomitopsis betulina* (Bull.) B.K.Cui et al. (2016)
Antibiotic, purgative, inflammation, viruses, styptic, antiseptic, cancer, HIV

Agarikon
*Fomitopsis officinalis* (Vill.) (1941)
Pulmonary diseases, rheumatism, asthma, viruses, antibacterial, tuberculosis

Red-Banded Polypore
*Fomitopsis spinicola* (Sw.) P.Karst. (1881)
Headaches, laxative, inflammation, antimicrobial, styptic

Reishi
*Ganoderma lucidum* (Curtis) P.Karst. (1881)
Inflammation, cancer, respiratory issues, asthma, insomnia, arthritis, allergies

Maitake, Hen of the woods
*Grifola frondosa* (Dicks.) Gray (1821)
Cancer, diabetes, tumors
Lion's Mane
_Hericium erinaceus_ (Bull.) Persoon (1797)
Memory, cognitive health, strength, vigor digestion, inflammation, Alzheimer's, anxiety

Chicken of the Woods
_Laetiporus sulphureus_
Cancer, hypoglycemia, inflammation, antioxidant, antimicrobial, high cholesterol, anticoagulant

Devil's Tooth
_Hydnum peckii_ (Banker) (1912)
Anti-coagulant, Antibacterial

Chaga
_Inonotus obliquus_ (Ach. ex Pers.) Pilát (1942)
Cancer, tumors, wounds, swelling, diabetes, antioxidant, antimicrobial, HIV, Hepatitis C

Shiitake
_Lentinula edodes_ (Berk.) Pegler (1976)
High cholesterol, antimicrobial, tumor, immune system, cancer

Tiger's Milk
_Lignosus rhinoceros_ (Cooke) Ryvarden (1972)
Neurodegenerative diseases, fever, itching, asthma, Cancer
**Chinese Caterpillar Fungus**
*Ophiocordyceps sinensis* (Berk.) (2007)
General health, endurance, stamina, immune issues, fatigue, Progesterone, kidney function

**Bitter Oyster Mushroom**
*Panellus stipticus* (Bull.) P. Karst. (1879)
Hemorrhaging

**Black Hoof Mushroom**
*Phellinus linteus* (Berk. MACurtis Teng) Teng (1963)
Cancer, menstruation & gastrointestinal issues, antioxidant, diabetes, antimicrobial, viruses, Inflammation, Myocardial ischemia reperfusion

**Oyster Mushroom**
*Pleurotus ostreatus* (Jacq.) P. Kumm. 1871
Diabetes, hyperlipidemia, cancer, infections, high cholesterol, fungal diseases, tumors, antioxidant, anti-aging

**Horn of Plenty**
*Pleurotus cornucopiae* (Paulet) Rolland (1910)
High Blood Pressure

**Kingtuber mushroom**
*Pleurotus tuber-regium* (Rumph. ex Fr.) Singer 1951
Cold, fever
Abalone
Diabetes

Matsutake
Tricholoma matsutake
Antimicrobial, Anti-inflammatory

Stout Camphor Fungus
Taiwanofungus camphoratus Wu et al. (2004)
Cancer, Allergies, Fatigue, Liver Issues, Antioxidant, Diabetes, Hepatitis B

NOT available English name
Tolypocladium inflatum W. Gams (1971)
Immunosuppressant, inflammation, fungal diseases, Psoriasis, Eczema, Crohn's Disease, Diabetes

Fig. 5. Some common mushrooms and their medical use https://www.gbif.org/species and photos from https://www.pexels.com/ and Wikipedia accessed on 18.04.2023.

According to Bhamri et al. (2022), the suggested mechanism of such medicinal mushrooms presented as follows:

1- Anti-cancer of Agaricus spp. by inhibiting cell proliferation of some cancer cell lines, antioxidant activities, and anti-inflammatory due to many metabolite components such as phenolic, sterols, indole compounds and nutraceuticals (Usman et al. 2021),

2- Antitumor, antioxidative, hypolipidemic, and antibacterial effects of Coprinus spp. by regulating the blood glucose level, hypoglycemic and antioxidative homeostasis due to forming carbohydrates, dietary fibers, and phenolic compounds (Stilinovic et al. 2020),

3- Anti-inflammatory, antitumor activity against both ascites as well as solid tumors of ethanolic extracts, and high antioxidant activity of Morchella spp. by increasing the cytotoxic effect and as immune-modulator because of organic acids, free fatty acids, flavonoids, triglycerides, and sterols (Dissanayake et al. 2021),

4- Antioxidant, antihyperglycemic, antimicrobial, iron-chelation, wound healing, cytotoxicity, anti-hypoxic, anti-acid inflammatory of Cortinarius spp. by inhibiting protein synthesis due to presence of amino acids, and orellanine (Meena et al. 2020), and

5- Antitumor, anti-inflammation, antivirus, antidiabetic, antioxidation, anti-hypertensive, immune-enhancing, immunomodulation, hyperlipidemia and hyperglycemia by Grifola spp. as an immunomodulator by the action of glucans, sesquiterpenes, and glycoproteins (Su et al. 2020).

Is the world of mushroom a real treasure for the scientific research? The answer simply is yes. This can explain in only one sentence that several mushrooms have a great potential as nutritional, pharmaceutical, and medicinal impacts. Regarding the nutritional value of mushrooms, they have enough and high values of many essential nutritional...
compounds like fiber, protein, carbohydrates and vitamins. Concerning the pharmaceutical attributes of mushrooms, they contain several metabolite compounds that can exhibit the pharmaceutical behavior in human like antifungal, antibacterial, antiviral, and tumor attenuating. Mushrooms are promising prebiotic agents due to their stimulation of the growth of gut microbiota, which confer health benefits to the host.

5. Conclusions
It could conclude that mushrooms have a distinguished nutritional value, due to their enough and high values of many essential nutritious compounds like protein, fiber, carbohydrates and vitamins. Mushrooms also have pharmaceutical and medicinal attributes, because of them contain many metabolite compounds, which can exhibit the pharmaceutical behavior in human like antifungal, antibacterial, antiviral, and tumor attenuating. Mushrooms are promising prebiotic agents due to their stimulation of the growth of gut microbiota, which confer health benefits to the host. Therefore, it is expected that enormous of research are needed to be carried out on different edible and medical mushrooms to discover more and more benefits of this treasure.

Ethics approval and consent to participate: This article does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication: All authors declare their consent for publication.

Conflicts of Interest: The author declares no conflict of interest.

Contribution of Authors: All authors shared in writing, editing and revising the MS and agree to its publication.

Acknowledgments: G. Törős and the authors thanks the 2020-1.1.2-PIACI-KFI-2020-00100 Project “Development of innovative food raw materials based on Maillard reaction by functional transformation of traditional and exotic mushrooms for food and medicinal purposes” for financializing and supporting this work.

6. References


MUSHROOM CULTIVATION SYSTEMS: EXPLORING ANTIMICROBIAL AND PREBIOTIC BENEFITS


Su CH, Lu MK, Lu TJ, Lai MN, Ng LT (2020). A (1→6)-Branch (1→4)-β-D-Glucan from *Grifola frondosa* Inhibits Lipopolysaccharide-Induced Cytokine Production in RAW264. 7 Macrophages by Binding to TLR2 Rather than Dectin-1 or CR3 Receptors. J. Nat. Prod. 83, 231–242. DOI: 10.1021/acs.jnatprod.9b00584


