DOI: https://doi.org/10.18524/2307-4663.2025.2(64).340385

УДК 615.33

**Ye. L. Kurianinov, O. Yu. Zinchenko**
Odesa I. I. Mechnikov National University,
2 Vsevoloda Zmiienka St, Odesa, 65082, Ukraine,
tel.: +380689836292, e-mail: eugenkuryaninov@gmail.com

# THE ANTIMICROBIAL PROMISE OF CULTIVATED MUSHROOMS: A REVIEW OF THE LAST DECADE'S FINDINGS

*A literature analysis was conducted on the antimicrobial potential of cultivated mushroom species. The review focuses on peer-reviewed studies, primarily from the past decade, that evaluate antimicrobial activity in cultivated edible and medicinal mushrooms. Analysis shows that species from the genera Pleurotus, Agaricus, Hericium, Flammulina, and Cordyceps produce metabolites effective against both Gram-positive and Gram-negative bacteria. Particular attention is given to metabolites like plectasin and cordycepin, which have demonstrated activity against Mycobacterium tuberculosis in experimental models. The findings underscore the promising role of cultivated mushrooms as a source of novel antimicrobial agents and reveal prospects for their practical use in pharmaceutical development.*

*Key words: cultivated mushrooms, antibiotic resistance, antimicrobial activity, secondary metabolites.*

Antimicrobial resistance (AMR) is one of the key public health threats globally. Numerous reports from international health organizations highlight that the uncontrolled use of antibiotics accelerates their loss of effectiveness, complicating the treatment of infections. It threatens the routine management of infectious diseases, increasing morbidity and mortality. According to the World Health Organization (WHO), bacteria with AMR caused directly 1.27 million deaths and contributed to 4.95 million deaths worldwide in 2019 [47].

Hospitalized patients, particularly those with traumatic injuries and prolonged stays, are at higher risk of colonization and infection by multidrug-resistant organisms (MDROs) – including methicillin-resistant *Staphylococcus aureus*, extended-spectrum β-lactamase producers, carbapenem-resistant *Enterobacter* and others. In conflict or mass-casualty situations, this problem is worsened by factors such as high rates of open wounds, frequent antibiotic exposure, disrupted infection-control practices, and patient transfers between facilities. Ukraine in recent years has met with severe pressures on its health system. Several clinical reports and surveillance activities show a higher prevalence of MDROs among wounded patients treated in hospitals.

Another growing concern is tuberculosis (TB). Globally, the World Health Organization estimates that in 2023, there were about 10.8 million new cases of TB and 1.25 million deaths. 2 of 5 cases are multidrug-resistant and extensively drug-resistant forms (MDR/XDR-TB), representing a major public health challenge. In Ukraine, more than 1300 new TB cases are reported monthly in 2025, with around 20–30% of these patients diagnosed with drug-resistant forms, contributing significantly to mortality and treatment complications. A prolonged therapy, the complexity of multidrug antibiotic regimens, and their considerable toxicity highlight the urgent need to explore alternative therapeutic agents against this disease [48, 49].

Antimicrobial activity of fungal metabolites is well-known for many decades but these studies were mostly focused on micromycetes leaving aside mushrooms whose complex life cycle can provide a promising field for the research on metabolites synthesized at different stages of life cycle. Under such conditions, mushrooms can be considered a poorly studied but promising source of bioactive secondary metabolites with antimicrobial activity.

**Fungi: classification and metabolic features**. Mushrooms are classified by taxonomic characteristics, but for practical purposes, they are often grouped by criteria related to human use. Four main categories are typically distinguished:

1) Edible mushrooms. These mushrooms have a long history of safe consumption, and the fruiting bodies have been part of the human diet for centuries in many cultures. They are considered safe either because they are inherently free of hazardous metabolites or because any potentially harmful compounds are effectively neutralized or removed by culinary processing, such as boiling or frying. Prominent examples are *Pleurotus ostreatus* (oyster mushroom) and *Agaricus bisporus* (button mushroom) [35].

2) Poisonous mushrooms. These species contain toxins that can cause severe illness or death even in small doses. Classic examples are *Amanita phalloides* (death cap) and *Galerina marginata* (deadly galerina), both of which produce amatoxins that affect RNA polymerase II, leading to fatal hepatotoxicity [11].

3) Medicinal mushrooms. This group includes species with documented pharmacological properties, including immunomodulatory and anti-inflammatory activity. Polypores such as *Ganoderma lucidum* (Reishi/Lingzhi) are rich in bioactive β-glucans and triterpenoids, which are used in traditional and modern medicine [15, 44].

4) Psychoactive mushrooms. These mushrooms contain neuroactive metabolites that alter perception of reality, cognitive function, and mental activity. *Psilocybe* species produce psilocybin, a tryptamine alkaloid that is currently being investigated in clinical trials for the treatment of psychiatric disorders. In contrast, *Amanita muscaria* (red fly agaric) contains isoxazole derivatives (muscimol and ibotenic acid) that are responsible for its hallucinogenic effects [40, 46].

From a cultivation perspective, fungi are divided into those that reliably form fruiting bodies under artificial conditions (in particular, xylotrophs, such as *Pleurotus,* and saprotrophs, such as *Agaricus*, which dominate global mushroom production), and those that do not form fruiting bodies under artificial conditions. Especially numerous are ectomycorrhizal fungi, whose life cycles require host

plants and complex symbioses. Despite recent advances, the cultivation of the latter remains a challenge and is only just beginning to develop [16, 28].

Fungal metabolism changes significantly at different stages of the life cycle, especially during the transition from vegetative mycelium to reproductive structures. During the mycelial phase, primary metabolic processes, including carbohydrate metabolism and enzyme production, dominate, which supports rapid biomass accumulation and substrate colonization. In contrast, fruiting bodies reorient metabolism towards morphogenesis and accumulation of secondary metabolites. Comparative studies between mycelial and fruiting body tissues of edible mushrooms (*A. bisporus*, *P. ostreatus*, *Lentinula edodes*) demonstrate significant variation in metabolite concentrations, indicating stage-specific biochemical adaptation [5].

The transition to reproductive development is also accompanied by differential gene expression and metabolite profiles. High-throughput transcriptomic analysis of *Lentinula edodes* has shown that thousands of genes are differentially expressed between the mycelium and mature fruiting body phases, with many transcripts associated with secondary metabolism and developmental regulation being upregulated in fruiting bodies [5]. Integrated metabolomic profiling confirms these shifts, documenting a significant accumulation of bioactive secondary metabolites, including terpenoids, phenolic compounds, and polysaccharides in fruiting bodies compared to mycelium, with notable variations even between early and late stages of development [12].

The metabolic diversity of fungi requires the use of various analytical approaches to study their secondary metabolites, since extracts obtained at different stages of development and using different solvents may yield different bioactivity profiles or none at all.

**Existing antibiotics of fungal origin.** Secondary metabolites of fungi demonstrate a variety of biological effects, serving as the basis for the development of antibiotics, antifungal agents, immunosuppressants, hormones, statins, and compounds for psychiatry and cosmetology in pharmaceuticals. Antimicrobial molecules first discovered in fungi have laid the foundation for a number of families of antibiotics. Despite the difficulties associated with the development of new antimicrobial agents, mushrooms remain a very promising source of antimicrobial compounds that deserve further investigation [6].

To date, a fairly wide range of fungal metabolites is known to have found practical applications. The classical examples are penicillin [10], cephalosporin [25] and fusidic acid [14] produced by micromycetes of genera *Penicillium*, *Cephalosporium* and *Ramularia*. Pleuromutilin produced by *Pleurotus mutilus* is not used directly but served as a base for obtaining several derivatives such as valnemulin [45] and tiamulin [36] used in veterinary medicine and retapamulin, a topical antibiotic for dermatologic application [31].

**Antimicrobial activity of metabolites from cultivated mushrooms.** To date, data on the spectrum of metabolites produced by cultivated mushrooms remain limited, despite considerable research interest over the past decades. This is largely due to the complexity of their life cycle, the challenges of reproducing all its stages under laboratory conditions, and the need to study metabolism at different stages to obtain a comprehensive picture. These factors necessitate the use

of various methods for extracting biologically active compounds from mushrooms. The most common approaches include obtaining culture filtrates, aqueous biomass extracts, or extraction using organic solvents.

A wide range of solvents are used for the extraction of secondary metabolites from fungi. In many studies, ethyl acetate, ethanol, and methanol are frequently reported as extraction solvents, while water, acetone or other solvents are used less often. Numerous investigations have highlighted differences in the biological activity of extracts, depending on the solvent applied.

Among the most cultivated mushrooms worldwide are *Agaricus bisporus* and *Pleurotus ostreatus*. Their antimicrobial properties have been investigated in a number of studies. For instance, a study conducted in France reported antimicrobial activity of ethyl acetate and methanol extracts towards *Staphylococcus aureus*, *Enterococcus faecalis*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Staphylococcus epidermidis* [19]. Ethyl acetate extracts from both mushroom species demonstrated inhibitory effects against all tested bacteria, while methanol extracts from *P. ostreatus* showed no significant activity. Notably, in the same study, non-cultivated, non-edible mushrooms such as *Fomitopsis pinicola*, *Lactarius helvus*, *Clitocybe nebularis*, *Scleroderma citrinum* and *Russula lepida* demonstrated stronger antimicrobial activity than cultivated species.

In another study, aqueous, acetone, and ethanol extracts of *Agaricus bisporus* and *Pleurotus sajor-caju* (currently classified as *Lentinus sajor-caju*) were evaluated. The antimicrobial activity of these extracts was tested towards six bacterial species: *E. coli*, *Bacillus subtilis*, *Bacillus cereus*, *Proteus vulgaris*, *S. aureus*, and *Micrococcus luteus*. In this investigation, all extracts demonstrated inhibitory effects against all tested bacteria [32].

The genus *Pleurotus* is widely cultivated across the world, and various representatives of this genus have been investigated for their antimicrobial activity.

Although *Pleurotus djamor* (pink oyster) and *Pleurotus florida* are primarily cultivated as edible mushrooms, recent studies demonstrate that their fruiting bodies and mycelial extracts possess measurable antimicrobial activity towards a range of Gram-positive and Gram-negative pathogens. Methanolic, ethanolic, and dichloromethane extracts have shown inhibitory effects *in vitro* against species such as *E. coli*, *P. aeruginosa*, *S. aureus* and others, with several studies reporting notable activity of mycelial dichloromethane extracts and methanolic fruiting-body extracts. These findings are supported by both targeted experimental reports and broader screenings published in the last decade [20, 21].

The complexity of fungal metabolism is well illustrated by the following studies: Andrade et al. demonstrated that the culture filtrate, obtained from submerged cultivation of *Pleurotus eryngii,* showed no detectable antimicrobial activity [4]. But another study [43] reported antimicrobial effects of ethanol, ethyl acetate and acetone extracts, prepared from fruiting bodies.

Polito et al. [33] analyzed ethanol extracts of *P. eryngii* using advanced analytical techniques. The secondary metabolites of these mushrooms included compounds of various classes – peptides, amino acids, carbohydrates, nucleic acids, organic acids, fatty acids, and flavonoids. The extracts demonstrated antimicrobial activity towards the majority of the bacterial test-strains used in the

study: *Clavibacter michiganensis*, *Bacillus megaterium*, *Pseudomonas viridiflava*, *Xanthomonas campestris* and *E. coli*.

The Golden Oyster mushroom (*Pleurotus citrinopileatus*) is recognized for its metabolic activity. From this species, glucosylceramide has been isolated and identified, demonstrating antimicrobial activity towards *Escherichia coli* and *Staphylococcus aureus*, with methanol used as the extraction solvent [27]. Ethyl acetate extracts of *P. citrinopileatus* have also been investigated, showing antimicrobial activity against *E. coli* and *S. aureus* [7]. In another study, methanolic extracts of *P. citrinopileatus* obtained from mushrooms cultivated on plant residues exhibited activity towards a wide range of microorganisms, including *Streptococcus mutans*, *Salmonella typhii*, *Candida tropicalis*, *Trichophyton* spp., *B. subtilis*, *P. aeruginosa*, *P. vulgaris*, *S. aureus*, and *E. coli* [22].

Recent studies have investigated various properties of *Pleurotus pulmonaris*, including antimicrobial, anticancer, and antioxidant activities. In these studies, the mushroom was cultivated on locally available plant residues (*Medicago sativa* L., *Prangos pabularia* Lindl. and *Poplar sawdust*), and methanolic extracts were subsequently prepared from the fruiting bodies to assess different bioactivities. Overall, the extracts demonstrated activity; however, it was noted that the degree of activity correlated with the type of substrate on which the fungus was cultivated: extract of the mushroom grown on *Medicago sativa* L. was the most active towards most Gram-positive and Gram-negative bacterial test-strains as well as dermatophytes [2].

In another investigation, the properties of exopolysaccharides produced by *P. pulmonaris* were examined. The fungus was grown using submerged fermentation in liquid media supplemented with different plant residues (groundnut shell, coconut husk, pineapple peel) and the type of plant substrate was found to influence the yield of secondary metabolites. The metabolites obtained in this manner exhibited antimicrobial properties against a range of bacterial strains such as *Shigella dysenteriae*, *E. coli*, *Salmonella typhi*, *Vibrio cholerae*, MRSA, *Bacillus subtilis*, *Candida albicans*, *Canida tropicalis* with the highest activity after cultivation on media containing groundnut shell and pineapple peel [30].

The most widely cultivated species of the *Pleurotus* genus is *Pleurotus ostreatus*. In most studies, ethyl acetate, ethanol, and methanol extracts have demonstrated antimicrobial activity; however, investigations that specifically identify the active compounds remain rare. It is known that the observed antimicrobial effects are associated with phenolic and polysaccharide compounds present in the fruiting bodies [17, 42].

*Hericium erinaceus*, also known as Lion's mane, has gained popularity relatively recently. Beyond its nutritional value, this mushroom possesses a range of medicinal properties. It produces compounds with neuroprotective and neuroregenerative effects, which are attributed to hericenones and erinacines – two groups of secondary metabolites isolated from *H. erinaceus* [9].

With regard to antimicrobial activity, it has been reported that its bioactive compounds can inhibit the growth of Gram-positive bacteria by disrupting bacterial membranes, preventing biofilm formation, and inhibiting bacterial enzymes. In contrast, its activity against Gram-negative bacteria is considerably lower [9]. Some

studies further suggest that secondary metabolites of this species may enhance the efficacy of existing antibiotics, reversing antibiotic susceptibility of resistant bacterial strains.

Close relatives of *H. erinaceus* – *Hericium coralloides* and *Hericium cirrhatum*, have also been studied. In one experiment examining the antimicrobial activity of culture filtrates and mycelia, all three species demonstrated inhibitory effects against *B. subtilis*, *E. coli*, *M. luteus*, and *P. aeruginosa*, while the activity against *S. aureus* was detected only for *H. coralloides* [26]. The study [29] that assessed ethyl acetate extracts of culture filtrates alongside ethanol mycelial extracts reported that antimicrobial activity varied depending on both the cultivation time of the fungus and the extraction method employed with the highest inhibitory effect on the culture of *S. aureus* after 14 days of mycelium cultivation.

Mushrooms of the genus *Flammulina* are among the most popular fungi in Asian countries. They have been cultivated for a long time and have become not only an integral part of traditional cuisine but also of traditional medicine. *Flammulina velutipes*, also known as Enoki, possesses a broad spectrum of bioactive compounds. Among these are the enokipodins – low-molecular-weight sesquiterpenes with demonstrated antimicrobial activity [23]. In addition, extracts of this mushroom have been reported to exhibit *in vitro* anticancer, immunomodulatory, neuroprotective, and hepatoprotective activities [38]. A close relative, *Flammulina filiformis* (golden enoki), shares similar characteristics. Extracts of this species have also been reported to display antimicrobial activity as well as potential neuroprotective properties [41].

A review article [3] summarizing earlier studies on the antimicrobial activity of various basidiomycetes highlights a wide range of fungi with demonstrated bioactivity. Among them are shiitake (*Lentinus edodes*), the common button mushroom (*Agaricus bisporus*), along with its close relatives (*Agaricus bitorquis*, *Agaricus essettei*), and the honey mushroom (*Armillaria mellea*), among many others. A broad spectrum of extraction solvents was employed in these studies, including acetone, chloroform, ethanol, ethyl acetate, methanol, dichloromethane, ether, xylene, and water.

It is also worth noting the peptide antibiotic plectasin, isolated from the fungus *Pseudoplectania nigrella*, which has demonstrated activity against bacterial strains resistant to conventional antibiotics [3]. A study investigating the antitubercular properties of plectasin and related peptides, in comparison with established antibiotics used in tuberculosis therapy, reported both significant activity and strong therapeutic potential [39]. Researchers have expressed particular optimism regarding this peptide antibiotic. In 2024, a study further elucidated the mechanism of action of plectasin [24]. Belonging to the class of defensins, plectasin targets the bacterial cell-wall precursor lipid II.

Mushrooms of the genus *Cordyceps* deserve special mention. This fungus is cultivated not so much as a food source, but rather as a functional food, for its bioactive compounds. Traditional medicine attributes various medicinal properties to mushrooms of this genus, and modern culture has added to the mushroom's popularity and made it one of the most expensive mushrooms. *C. militaris* is a cultivated species of *Cordyceps*. Its metabolites have been studied and have

been shown to have antiviral, antitumor, immunomodulatory, and antimicrobial properties [34]. In particular, cordycepin (3′-deoxyadenosine) inhibits the growth of *Mycobacterium tuberculosis* bacteria [18]. Another study examined extracts of *C. militaris* and demonstrated antimicrobial activity against Gram-positive and Gram-negative bacteria, as well as antitumor activity [1]. *C. militaris* is also capable of producing statins (e.g., lovastatin), neurotransmitters (e.g., GABA), non-proteinogenic metabolically active amino acids (e.g., ergothioneine), cordycepic acid (D-mannitol), and other active compounds [8]. Further study of the metabolites of this mushroom may improve our capabilities in regenerative medicine and improve quality of life.

Recent advances in exploring antimicrobial potential of cultivated fungi are summarized in table 1.

Presented data demonstrate that in most cases identification of chemical nature of active compounds was not carried out. Nevertheless, the observed inhibitory effect on a broad spectrum of pathogens indicates the relevance of further research. The activity of extracts might be mediated by a cocktail of biologically active compounds which opens broad perspectives for drug development. Moreover, it is not always possible to reproduce all stages of the fungal life cycle under laboratory cultivation conditions, which currently limits the ability to study the full spectrum of biologically active fungal metabolites.

Mushrooms are characterized by a rich diversity of bioactive metabolites, but as a group of organisms they remain poorly studied. Only a small fraction of fungal species can be cultivated under laboratory, domestic, or industrial conditions, and even fewer are capable of reliably producing fruiting bodies. Studies indicate that the production of secondary metabolites can vary substantially across different developmental stages of the fungus. In terms of antimicrobial activity, young fruiting bodies are of particular interest, as fungi tend to accumulate antimicrobial compounds in these structures as a means of defense.

Research demonstrates that the outcomes of antimicrobial assays are highly dependent on multiple parameters, including the choice of solvent (e.g., ethyl acetate, ethanol, or methanol), the cultivation method (e.g., submerged culture, Petri plate culture, or agricultural residues), and the developmental stage of the fungus (e.g., primary mycelium, liquid-culture mycelium, or fruiting body). Only a limited number of studies have advanced beyond demonstrating antimicrobial activity *in vitro* to the comprehensive characterization of fungal metabolites.

Limited studies on the antimicrobial properties of fungi are aimed at identifying compounds active against pathogens of high social significance. Nevertheless, two metabolites – plectasin and cordycepin – have demonstrated activity against *Mycobacterium tuberculosis*.

Another critical issue is the lack of standardized research methodologies. In most publications, extraction methods are described briefly, often omitting essential details. It is well known that many metabolites are heat-sensitive, which can affect the composition of the extracted compounds. Moreover, active substances are frequently present in low concentrations, requiring substantial amounts of fungal biomass and solvent volumes, as well as subsequent concentration steps to achieve sufficient yield. In many cases, failure to account for these factors leads to inconsistent and contradictory results.

Table 1

**Antimicrobial activity of cultivated fungi metabolites discovered in the past decade**

| Mushroom species | Source of extract | Extractant | Active compound | Activity | Reference |
|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 |
| *Agaricus bisporus* | Fruiting body | Ethyl acetate, methanol | N/I | *Staphylococcus aureus, Enterococcus faecalis*, *Escherichia coli*, *Pseudomonas aeruginosa, Staphylococcus epidermidis* | [19] |
| *Agaricus bisporus* | Fruiting body | Ethanol, acetone, water | N/I | *E. coli, Proteus vulgaris, Bacillus cereus,Bacillus subtilis, Staphylococcus aureus, Micrococcus luteus* | [32] |
| *Pleurotus ostreatus* | Fruiting body | Ethyl acetate | N/I | *S. aureus*, *E. faecalis,*, *E. coli, P. aeruginosa, S. epidermidis* | [19] |
| *Lentinus sajor-caju (Pleurotus sajor-caju)* | Fruiting body | Ethanol, acetone, water | N/I | *E. coli, P. vulgaris, Bacillus cereus, B. subtilis, S. aureus, M. luteus* | [32] |
| *Pleurotus eryngii* | Fruiting body | Ethanol, acetone, ethyl acetate | N/I | *M. luteus, S. aureus, B. subtilis, P. aeruginosa, Enterobacter cloacae, E. coli* | [43] |
| *Pleurotus eryngii* | Fruiting body | Ethanol | N/I | *Clavibacter michiganensis*, *Pseudomonas viridiflava*, *E. coli* | [33] |
| *Pleurotus djamor* | Mycelium | Dichloro-methane | N/I | *S. aureus Streptococcus mutans, B. subtilis, E. coli, Klebsiella pneumonia, P. aeruginosa, Vibrio cholera, Salmonella typhi, Pichia stipitis, Candida albicans, Aspergillus niger, Aspergillus terreus)* | [20] |
| *Pleurotus florida* | Mycelium | Dichloro-methane | N/I | *S. aureus, Streptococcus mutans, B. subtilis, E. coli, K. pneumonia, P. aeruginosa, Vibrio cholera, Salmonella typhi, Pichia stipitis, Candida albicans, Aspergillus niger, Aspergillus terreus)* | [20] |
| *Pleurotus djamor* | Fruiting body | Methanol | N/I | *B. subtilis, Proteus vulgaris, S. mutans, S. typhi, P. aeruginosa, S. aureus, E. coli, Trichophyton sp., C. tropicalis* | [21] |
| *Pleurotus citrinopileatus* | Liquid culture filtrate | Ethyl acetate | N/I | *E. coli, S. aureus* | [7] |
| *Pleurotus citrinopileatus* | Fruiting body | Methanol | Glucosyl-ceramide | *S. mutans, S. thypii, C. tropicalis Trichopyton sp., B. subtilis, P. aeruginosa, P. vulgaris, S. aureus, E. coli* | [22] |
| *Pleurotus pulmonarius* | Fruiting body | Methanol | N/I | *P. aeruginosa, E. coli, S. aureus, S. mutans, P. vulgaris, K. pneumoniae, C. tropicalis, Epi-dermophyton sp., Trichophyton sp.* | [2] |

Продовження таблиці 1

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| *Pleurotus pulmonarius* | Mycelium | Ethanol | Exopoly-saccharides | *Shigella dysenteriae, E. coli, S. typhi, Vibrio cholerae, Methicillin resistant S. aureus, B. subtilis, C. albicans, C. tropicalis* | [30] |
| *Pleurotus ostreatus* | Fruiting body | Methanol, chloroform, water | N/I | *S. aureus, M. luteus, E. coli, C. albicans.* | [17] |
| *Pleurotus ostreatus* | Fruiting body | Methanol | N/I | *S. aureus, E. coli, Neisseria gonorrhoeae,* | [42] |
| *Hericium erinaceus* | Mycelium, cultural liquid | Filtration | N/I | *B. subtilis, E. coli, M. luteus, P. aeruginosa, S. aureus.* | [26] |
| *Hericium coralloides* | Mycelium, cultural liquid | Filtration | N/I | *B. subtilis, E. coli, M. luteus, P. aeruginosa, S. aureus.* | [26] |
| *Hericium cirrhatum* | Mycelium, cultural liquid | Filtration | N/I | *B. subtilis, E. coli, M. luteus, P. aeruginosa.* | [26] |
| *Hericium erinaceus* | Mycelium, cultural liquid | Ethanol, ethyl acetate | N/I | *B. subtilis, P. aeruginosa, S. aureus, E. coli, K. pneumoniae* | [29] |
| *Hericium coralloides* | Mycelium, cultural liquid | Ethanol, ethyl acetate | N/I | *B. subtilis, P. aeruginosa, S. aureus, E. coli, K. pneumoniae* | [29] |
| *Hericium cirrhatum* | Mycelium, cultural liquid | Ethanol, ethyl acetate | N/I | *B. subtilis, P. aeruginosa, S. aureus, E. coli, K. pneumoniae* | [29] |
| *Flammulina velutipes* | Mycelium | Methanol, chloroform | Enokipodins | *S. aureus, P. aeruginosa, B. sibtilis* | [23] |
| *Lentinus edodes* | Fruiting body | Methanol, ethanol, chloroform, ethyl acetate. | N/I | *Actinomyces naeslundii, Actinomyces viscosus, Bacillus cereus, Bacillus megaterium, Bacillus pumilis, Bacillus subtilis, Enterococcus faecalis, Enterococcus faecium, Lactobacillus casei, Listeria innocua, Listeria monocytogenes, Staphylococcus aureus, Staphylococcus epidermidis, Streptococcus gordonii, Streptococcus mitis, Streptococcus mutans, Streptococcus oralis, Streptococcus pyogenes, Streptococcus salivarius, Streptococcus sanguinis, Streptococcus sobrinus, Micrococcus luteus* | [3] |
| *Cordyceps militaris* | Fruiting body | n-hexane | Cordycepin | *S. aureus, S. typhi, E. coli* | [8] |

Note: N/I – non identified.

An additional aspect that remains insufficiently addressed is the activity of fungal extracts towards antibiotic-resistant bacterial strains. Hospitals represent a primary reservoir for multidrug-resistant pathogens, and the inclusion of such strains in antimicrobial screening could yield valuable insights and identify promising directions for further drug development.

Despite the encouraging discoveries reported thus far, fungi and their secondary metabolites still require more systematic and in-depth investigation.

**Є. Л. Кур'янінов, О. Ю. Зінченко**
Одеський національний університет імені І. І. Мечникова,
вул. Всеволода Змієнка, 2, м. Одеса, 65082, Україна,
тел.: +380689836292, e-mail: eugenkuryaninov@gmail.com

## АНТИМІКРОБНИЙ ПОТЕНЦІАЛ КУЛЬТИВОВАНИХ ГРИБІВ: ОГЛЯД ДОСЛІДЖЕНЬ ОСТАННЬОГО ДЕСЯТИЛІТТЯ

**Резюме**

*Здійснено аналіз літератури щодо антимікробного потенціалу видів культивованих грибів. Огляд зосереджений на рецензованих наукових публікаціях, переважно за останнє десятиліття, які оцінюють антимікробну активність їстівних і лікарських культивованих грибів. Аналіз показує, що види з родів Pleurotus, Agaricus, Hericium, Flammulina та Cordyceps продукують метаболіти, ефективні як щодо грампозитивних, так і грамнегативних бактерій. Особливої уваги заслуговують плектацин і кордицепін, які продемонстрували активність щодо Mycobacterium tuberculosis в експериментальних моделях. Отримані результати підкреслюють перспективну роль культивованих грибів як джерела нових антимікробних агентів.*

*Ключові слова: культивовані гриби, антимікробна резистентність, антимікробна активність, вторинні метаболіти.*

### СПИСОК ВИКОРИСТАНОЇ ЛІТЕРАТУРИ

1. Afzal M., Abusalah M.A.H.A., Shehzadi N., et al. Investigation of biometabolites and novel antimicrobial peptides derived from promising source *Cordyceps militaris* and effect of non-small cell lung cancer genes computationally // PLoS One. – 2025. – V. 20 (1). – P. e0310103.
2. Akyüz M., İnci Ş., Kirbag S. Evaluation of antimicrobial, antioxidant, cytotoxic and DNA protective effects of oyster mushroom: *Pleurotus pulmonarius* (Fr.) Quel. // Arab J. Sci. Eng. – 2022. – V. 48. – P. 1–11.
3. Alves M.J., Ferreira I.C., Dias J., Teixeira V., Martins A., Pintado M. A review on antimicrobial activity of mushroom (*Basidiomycetes*) extracts and isolated compounds // Planta Med. – 2012. – V. 78 (16). – P. 1707–1718.
4. Andrade C., Oliveira A., Vieira V., Frazão B., Gurgel R., Oliveira R., Kirsch L. Antimicrobial activity of the edible mushroom *Pleurotus eryngii* (DC.) Quél grown in liquid medium // Acta Sci. Biol. Sci. – 2021. – V. 43. – P. e58474.

5. Berger R.G., Bordewick S., Krahe N.K., Ersoy F. Mycelium vs. fruiting bodies of edible fungi – a comparison of metabolites // Microorganisms. – 2022. – V. 10 (7). – P. 1379.
6. Bills G.F., Gloer J.B. Biologically active secondary metabolites from the fungi // Microbiol. Spectr. – 2016. – V. 4 (6). – P. FUNK-0009-2016.
7. Chomcheon P., Kheawkum B., Sriwiset P., Dulsamphan S., Dulsamphan C. Antibacterial activity of crude extracts from edible mushrooms *Pleurotus citrinopileatus* and *Tricholoma crassum* Berk. // Thai J. Pharm. Sci. – 2013. – V. 37. – P. 107–111.
8. Chou Y-C., Sung T-H., Hou S-J., et al. Current progress regarding *Cordyceps militaris*, its metabolite function, and its production // Appl. Sci. – 2024. – V. 14 (11). – P. 4610.
9. Contato A.G., Conte-Junior C.A. Lion's Mane Mushroom (*Hericium erinaceus*): A neuroprotective fungus with antioxidant, anti-inflammatory, and antimicrobial potential – a narrative review // Nutrients. – 2025. – V. 17 (8). – P. 1307.
10. Correia J., Borges A., Simões M., Simões L.C. Beyond penicillin: the potential of filamentous fungi for drug discovery in the age of antibiotic resistance // Antibiotics. – 2023. – V. 12 (8). – P. 1250.
11. Diaz J.H. Amatoxin-containing mushroom poisonings: species, toxidromes, treatments, and outcomes // Wilderness Environ. Med. – 2018. – V. 29 (1). – P. 111–118.
12. Du F., Zou Y., Hu Q., Jing Y., Yang X. Metabolic profiling of *Pleurotus tuoliensis* during mycelium physiological maturation and exploration on a potential indicator of mycelial maturation // Front. Microbiol. – 2019. – V. 9. – P. 3274.
13. Fang H.Q., Zeng J., Wang S.K., et al. Discovery of novel pleuromutilin derivatives as potent antibacterial agents for the treatment of MRSA infection // Molecules. – 2022. – V. 27 (3). – P. 931.
14. Fernandes P. Fusidic acid: a bacterial elongation factor inhibitor for the oral treatment of acute and chronic staphylococcal infections // Cold Spring Harb. Perspect. Med. – 2016. – V. 6 (1). – P. a025437.
15. Galappaththi M.C.A., Patabendige N.M., Premarathne B.M., Jayasinghe C.D., Attanayake A.P., Ediriweera M.K., et al. A review of *Ganoderma* triterpenoids and their bioactivities // Biomolecules. – 2022. – V. 13 (1). – P. 24.
16. Guerin-Laguette A. Successes and challenges in the sustainable cultivation of edible mycorrhizal fungi – furthering the dream // Mycoscience. – 2021. – V. 62 (1). – P. 10–28.
17. Hamad D., El-Sayed H., Ahmed W., Sonbol H., Ramadan M.A.H. GC-MS analysis of potentially volatile compounds of *Pleurotus ostreatus* polar extract: in vitro antimicrobial, cytotoxic, immunomodulatory, and antioxidant activities // Front. Microbiol. – 2022. – V. 13. – P. 834525.
18. Huang F., Li W., Xu H., Qin H., He Z.G. Cordycepin kills *Mycobacterium tuberculosis* through hijacking the bacterial adenosine kinase // PLoS One. – 2019. – V. 14 (6). – P. e0218449.

19. Huguet C., Bourjot M., Bellanger J.M., Prévost G., Urbain A. Screening for antibacterial activity of French mushrooms against pathogenic and multidrug resistant bacteria // Appl. Sci. – 2022. – V. 12 (10). – P. 5229.
20. Illuri R., Eyini M., Kumar M., et al. Bio-prospective potential of *Pleurotus djamor* and *Pleurotus florida* mycelial extracts towards Gram positive and Gram negative microbial pathogens causing infectious disease // J. Infect. Public Health. – 2022. – V. 15 (2). – P. 297–306.
21. Inci Ş., Akyüz M., Kirbag S. Antimicrobial, antioxidant, cytotoxicity and DNA protective properties of the pink oyster mushroom, *Pleurotus djamor* (Agaricomycetes) // Int. J. Med. Mushrooms. – 2023. – V. 25 (2). – P. 55–66.
22. Inci Ş., Kirbag S., Akyüz M. Medicinal properties of the golden oyster mushroom, *Pleurotus citrinopileatus* (Agaricomycetes), grown on local agricultural wastes in Turkey // Int. J. Med. Mushrooms. – 2022. – V. 24 (5). – P. 33–43.
23. Ishikawa N., Yamaji K., Ishimoto H., et al. Production of enokipodins A, B, C, and D: a new group of antimicrobial metabolites from mycelial culture of *Flammulina velutipes* // Mycoscience. – 2005. – V. 46. – P. 39–45.
24. Jekhmane S., Derks M.G.N., Maity S., et al. Host defence peptide plectasin targets bacterial cell wall precursor lipid II by a calcium-sensitive supramolecular mechanism // Nat. Microbiol. – 2024. – V. 9 (8). – P. 1778–1791.
25. Lin X., Kück U. Cephalosporins as key lead generation beta-lactam antibiotics // Appl. Microbiol. Biotechnol. – 2022. – V. 106 (24). – P. 8007–8020.
26. Lomberg M., Krupodorova T., Krasinko V., Mykchaylova O. The antibacterial activity of culture filtrates and mycelia of selected strains of macromycetes from the genus *Hericium* // Bot. Serb. – 2023. – V. 47 (2). – P. 241–249.
27. Meng T.X., Ishikawa H., Shimizu K., et al. A glucosylceramide with antimicrobial activity from the edible mushroom *Pleurotus citrinopileatus* // J. Wood Sci. – 2012. – V. 58 (1). – P. 81–86.
28. Nakazawa T., Kawauchi M., Otsuka Y., et al. *Pleurotus ostreatus* as a model mushroom in genetics, cell biology, and material sciences // Appl. Microbiol. Biotechnol. – 2024. – V. 108 (1). – P. 217.
29. Narmuratova Z., Bisko N., Mustafin K., et al. Screening of medicinal mushroom strains with antimicrobial activity and polysaccharides production // Turk J. Biochem. – 2023. – V. 48, № 3. – P. 290–297.
30. Ogidi C.O., et al. Bioactivity assessment of exopolysaccharides produced by *Pleurotus pulmonarius* in submerged culture with different agro-waste residues // Heliyon. – 2020. – V. 6 (12). – P. e05685.
31. Parish L.C., Parish J.L. Retapamulin: a new topical antibiotic for the treatment of uncomplicated skin infections // Drugs Today (Barc). – 2008. – V. 2 (44). – P. 91–102. doi: 10.1358/dot.2008.44.2.1153446. PMID: 18389088.
32. Patil S., Kulkarni T., Dhramadhikari N., Girish Pathade B.H. Antimicrobial activity of cultivated edible mushrooms, *Agaricus bisporus* and *Pleurotus sajor caju* // J. Neonatal Surg. – 2025. – V. 14 (24s). – P. 481–491.
33. Polito F., De Martino L., Mirabile G., et al. Composition and antimicrobial

activity of hydroalcoholic extracts of *Pleurotus eryngii* var. *ferulae* and *P. eryngii* var. *elaeoselini* // Front. Chem. – 2024. – V. 12. – P. 1498787.
34. Qu S-L., Li S-S., Li D., Zhao P-J. Metabolites and their bioactivities from the genus *Cordyceps* // Microorganisms. – 2022. – V. 10 (8). – P. 1489.
35. Raman J., Jang K.Y., Oh Y.L., Oh M., Im J.H., Lakshmanan H., et al. Cultivation and nutritional value of prominent *Pleurotus* spp.: an overview // Mycobiology. – 2021. – V. 49 (1). – P. 1–14.
36. Sartini I., Vercelli C., Lebkowska-Wieruszewska B., Lisowski A., Fadel C., Poapolathep A., Dessì F., Giorgi M. Pharmacokinetics and antibacterial activity of tiamulin after single and multiple oral administrations in geese // Vet Anim Sci. – 2023. – V. 22. – P. 100317. doi: 10.1016/j.vas.2023.100317. PMID: 37920697; PMCID: PMC1061876.
37. Sovrani V., de Jesus L.I., Simas-Tosin F.F., Smiderle F.R., Iacomini M. Structural characterization and rheological properties of a gel-like β-D-glucan from *Pholiota nameko* // Carbohydr. Polym. – 2017. – V. 169. – P. 1–8.
38. Tang C., Hoo P.C., Tan L.T., et al. Golden Needle Mushroom: A Culinary Medicine with Evidenced-Based Biological Activities and Health Promoting Properties // Front. Pharmacol. – 2016. – V. 7. – P. 474.
39. Tenland E., Krishnan N., Rönnholm A., et al. A novel derivative of the fungal antimicrobial peptide plectasin is active against *Mycobacterium tuberculosis* // Tuberculosis (Edinb). – 2018. – V. 113. – P. 231–238.
40. Winkelman M.J. *Amanita muscaria*: Fly agaric history, mythology and pharmacology // J. Psychedelic Stud. – 2022. – V. 6 (1). – P. 1–4.
41. Wu S., Chen X., Ren J., Liu P., Yan Q., Chen Z. Cuparene-type sesquiterpenes with neuroprotective activities from the edible mushroom *Flammulina filiformis* // Fitoterapia. – 2024. – V. 179. – P. 106235.
42. Yakobi S.H., Mkhize S., Pooe O.J. Screening of antimicrobial properties and bioactive compounds of *Pleurotus ostreatus* extracts against *Staphylococcus aureus*, *Escherichia coli*, and *Neisseria gonorrhoeae* // Biochem. Res. Int. – 2023. – V. 4. – P. 1777039.
43. Yu E.J., Han S.R., Kim K.H., Park B.R., Lim K.O., Oh T.J. Antibacterial and antioxidant activity of *Pleurotus eryngii* extracts // Indian J. Public Health Res. Dev. – 2018. – V. 9. – P. 2206.
44. Zhong Y., Tan P., Lin H., Huang Y., Zhang H., Li D., et al. A review of *Ganoderma lucidum* polysaccharide: preparations, structures, physicochemical properties and application // Foods. – 2024. – V. 13 (17). – P. 2665.
45. Zhu X., Xu S., Lu L., Wang S., Zhao Q., Li D., Li J., Zhao H., Xu B. Preparation, characterization, and in vivo evaluation of a polymorphic form of valnemulin hydrogen tartrate // J Vet Sci. – 2019. – V. 2 (20). – P. e16. https://doi.org/10.4142/jvs.2019.20.e16.
46. https://nida.nih.gov/research-topics/psilocybin-magic-mushrooms. 24 January 2024
47. https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance.
48. https://www.who.int/news-room/fact-sheets/detail/tuberculosis.
49. https://www.phc.org.ua/news/statistika-tuberkulozu-v-ukraini-berezen-2025-roku.

## REFERENCES


1. Afzal M, Abusalah MAHA, Shehzadi N, Absar M, Ahmed N, et al. Investigation of biometabolites and novel antimicrobial peptides derived from promising source *Cordyceps militaris* and effect of non-small cell lung cancer genes computationally. PLoS One. 2025;20(1):e0310103. doi:10.1371/journal.pone.0310103.
2. Akyüz M, İnci Ş, Kirbag S. Evaluation of antimicrobial, antioxidant, cytotoxic and DNA protective effects of oyster mushroom: *Pleurotus pulmonarius* (Fr.) Quel. Arab J Sci Eng. 2022;1-11. doi:10.1007/s13369-022-07418-9.
3. Alves MJ, Ferreira IC, Dias J, Teixeira V, Martins A, Pintado M. A review on antimicrobial activity of mushroom (*Basidiomycetes*) extracts and isolated compounds. Planta Med. 2012;78(16):1707-1718. doi:10.1055/s-0032-1315370.
4. Andrade C, Oliveira A, Vieira V, Frazão B, Gurgel R, Oliveira R, Kirsch L. Antimicrobial activity of the edible mushroom *Pleurotus eryngii* (DC.) Quél grown in liquid medium. Acta Sci Biol Sci. 2021; 43: e58474. doi:10.4025/actascibiolsci.v43i1.58474.
5. Berger RG, Bordewick S, Krahe NK, Ersoy F. Mycelium vs. fruiting bodies of edible fungi – a comparison of metabolites. Microorganisms. 2022;10(7):1379. doi:10.3390/microorganisms10071379.
6. Bills GF, Gloer JB. Biologically active secondary metabolites from the fungi. Microbiol Spectr. 2016;4(6):FUNK-0009-2016. doi:10.1128/microbiolspec.FUNK-0009-2016.
7. Chomcheon P, Kheawkum B, Sriwiset P, Dulsamphan S, Dulsamphan C. Antibacterial activity of crude extracts from edible mushrooms *Pleurotus citrinopileatus* and *Tricholoma crassum* Berk. Thai J Pharm Sci. 2013;37:107-111.
8. Chou Y-C, Sung T-H, Hou S-J, Khumsupan D, Santoso SP, Cheng K-C, Lin S-P. Current progress regarding *Cordyceps militaris*, its metabolite function, and its production. Appl Sci. 2024;14(11):4610. doi:10.3390/app14114610.
9. Contato AG, Conte-Junior CA. Lion's Mane Mushroom (*Hericium erinaceus*): A neuroprotective fungus with antioxidant, anti-inflammatory, and antimicrobial potential – a narrative review. Nutrients. 2025;17(8):1307. doi:10.3390/nu17081307.
10. Correia J, Borges A, Simões M, Simões LC. Beyond penicillin: the potential of filamentous fungi for drug discovery in the age of antibiotic resistance. Antibiotics (Basel). 2023;12(8):1250. doi:10.3390/antibiotics12081250.
11. Diaz JH. Amatoxin-containing mushroom poisonings: species, toxidromes, treatments, and outcomes. Wilderness Environ Med. 2018;29(1):111-8. doi:10.1016/j.wem.2017.10.002. PMID:29325729.
12. Du F, Zou Y, Hu Q, Jing Y, Yang X. Metabolic profiling of *Pleurotus tuoliensis* during mycelium physiological maturation and exploration on a potential indicator of mycelial maturation. Front Microbiol. 2019;9:3274. doi:10.3389/fmicb.2018.03274.
13. Fang HQ, Zeng J, Wang SK, et al. Discovery of novel pleuromutilin derivatives as potent antibacterial agents for the treatment of MRSA infection. Molecules. 2022;27(3):931. doi:10.3390/molecules27030931.

14. Fernandes P. Fusidic acid: a bacterial elongation factor inhibitor for the oral treatment of acute and chronic staphylococcal infections. Cold Spring Harb Perspect Med. 2016;6(1):a025437. doi:10.1101/cshperspect.a025437.
15. Galappaththi MCA, Patabendige NM, Premarathne BM, Jayasinghe CD, Attanayake AP, Ediriweera MK, et al. A review of *Ganoderma* triterpenoids and their bioactivities. Biomolecules. 2022;13(1):24. doi:10.3390/biom13010024.
16. Guerin-Laguette A. Successes and challenges in the sustainable cultivation of edible mycorrhizal fungi - furthering the dream. Mycoscience. 2021;62(1):10-28. doi:10.47371/mycosci.2020.11.007.
17. Hamad D, El-Sayed H, Ahmed W, Sonbol H, Ramadan MAH. GC-MS analysis of potentially volatile compounds of *Pleurotus ostreatus* polar extract: in vitro antimicrobial, cytotoxic, immunomodulatory, and antioxidant activities. Front Microbiol. 2022;13:834525. doi:10.3389/fmicb.2022.834525.
18. Huang F, Li W, Xu H, Qin H, He ZG. Cordycepin kills *Mycobacterium tuberculosis* through hijacking the bacterial adenosine kinase. PLoS One. 2019;14(6):e0218449. doi:10.1371/journal.pone.0218449.
19. Huguet C, Bourjot M, Bellanger JM, Prévost G, Urbain A. Screening for antibacterial activity of French mushrooms against pathogenic and multidrug resistant bacteria. Appl Sci. 2022;12(10):5229. doi:10.3390/app12105229.
20. Illuri R, Eyini M, Kumar M, Suresh Babu R, Prema P, Nguyen VH, Bukhari NA, Hatamleh AA, Balaji P. Bio-prospective potential of *Pleurotus djamor* and *Pleurotus florida* mycelial extracts towards Gram positive and Gram negative microbial pathogens causing infectious disease. J Infect Public Health. 2022;15(2):297-306. doi:10.1016/j.jiph.2021.10.012.
21. Inci Ş, Akyüz M, Kirbag S. Antimicrobial, antioxidant, cytotoxicity and DNA protective properties of the pink oyster mushroom, *Pleurotus djamor* (*Agaricomycetes*). Int J Med Mushrooms. 2023;25(2):55-66. doi:10.1615/IntJMedMushrooms.2022046706.
22. Inci Ş, Kirbag S, Akyüz M. Medicinal properties of the golden oyster mushroom, *Pleurotus citrinopileatus* (*Agaricomycetes*), grown on local agricultural wastes in Turkey. Int J Med Mushrooms. 2022;24(5):33-43. doi:10.1615/IntJMedMushrooms.2022039745.
23. Ishikawa N, Yamaji K, Ishimoto H, et al. Production of enokipodins A, B, C, and D: a new group of antimicrobial metabolites from mycelial culture of *Flammulina velutipes*. Mycoscience. 2005;46:39-45. doi:10.1007/s10267-004-0208-6.
24. Jekhmane S, Derks MGN, Maity S, et al. Host defence peptide plectasin targets bacterial cell wall precursor lipid II by a calcium-sensitive supramolecular mechanism. Nat Microbiol. 2024;9(8):1778-1791. doi:10.1038/s41564-024-01696-9.
25. Lin X, Kück U. Cephalosporins as key lead generation beta-lactam antibiotics. Appl Microbiol Biotechnol. 2022;106(24):8007-20. doi:10.1007/s00253-022-12272-8.
26. Lomberg M, Krupodorova T, Krasinko V, Mykchaylova O. The antibacterial activity of culture filtrates and mycelia of selected strains of macromycetes

from the genus Hericium. Bot Serb. 2023;47(2):241-9. doi:10.2298/BOTSERB2302241L.
27. Meng TX, Ishikawa H, Shimizu K, et al. A glucosylceramide with antimicrobial activity from the edible mushroom *Pleurotus citrinopileatus*. J Wood Sci. 2012;58(1):81-86. doi:10.1007/s10086-011-1213-y.
28. Nakazawa T, Kawauchi M, Otsuka Y, et al. *Pleurotus ostreatus* as a model mushroom in genetics, cell biology, and material sciences. Appl Microbiol Biotechnol. 2024;108(1):217. doi:10.1007/s00253-024-13034-4.
29. Narmuratova Z, Bisko N, Mustafin K, Al-Maali G, Kerner A, Bondaruk S, Suleimenova Z, Kalieva A, Akhmetsadykov N, Zhakipbekova A, Lomberg M. Screening of medicinal mushroom strains with antimicrobial activity and polysaccharides production. Turk J Biochem. 2023;48(3):290-7. doi:10.1515/tjb-2022-0235.
30. Ogidi CO, et al. Bioactivity assessment of exopolysaccharides produced by *Pleurotus pulmonarius* in submerged culture with different agro-waste residues. Heliyon. 2020;6(12):e05685. doi:10.1016/j.heliyon.2020.e05685.
31. Parish LC, Parish JL. Retapamulin: a new topical antibiotic for the treatment of uncomplicated skin infections. Drugs Today (Barc). 2008 Feb;44(2):91-102. doi: 10.1358/dot.2008.44.2.1153446. PMID: 18389088
32. Patil S, Kulkarni T, Dhramadhikari N, Girish Pathade BH. Antimicrobial activity of cultivated edible mushrooms, *Agaricus bisporus* and *Pleurotus sajor caju*. J Neonatal Surg. 2025;14(24s):481-491.
33. Polito F, De Martino L, Mirabile G, Venturella G, Gargano ML, De Feo V, Elshafie HS, Camele I. Composition and antimicrobial activity of hydroalcoholic extracts of *Pleurotus eryngii* var. *ferulae* and *P. eryngii* var. *elaeoselini*. Front Chem. 2024;12:1498787. doi:10.3389/fchem.2024.1498787.
34. Qu S-L, Li S-S, Li D, Zhao P-J. Metabolites and their bioactivities from the genus *Cordyceps*. Microorganisms. 2022;10(8):1489. doi:10.3390/microorganisms10081489.
35. Raman J, Jang KY, Oh YL, Oh M, Im JH, Lakshmanan H, et al. Cultivation and nutritional value of prominent *Pleurotus* spp.: an overview. Mycobiology. 2021;49(1):1-14. doi:10.1080/12298093.2020.1835142.
36. Sartini I, Vercelli C, Lebkowska-Wieruszewska B, Lisowski A, Fadel C, Poapolathep A, Dessì F, Giorgi M. Pharmacokinetics and antibacterial activity of tiamulin after single and multiple oral administrations in geese. Vet Anim Sci. 2023 Oct 21;22:100317. doi: 10.1016/j.vas.2023.100317. PMID: 37920697; PMCID: PMC1061876
37. Sovrani V, de Jesus LI, Simas-Tosin FF, Smiderle FR, Iacomini M. Structural characterization and rheological properties of a gel-like β-d-glucan from *Pholiota nameko*. Carbohydr Polym. 2017;169:1-8. doi:10.1016/j.carbpol.2017.03.093.
38. Tang C, Hoo PC, Tan LT, et al. Golden Needle Mushroom: A Culinary Medicine with Evidenced-Based Biological Activities and Health Promoting Properties. Front Pharmacol. 2016;7:474. doi:10.3389/fphar.2016.00474.
39. Tenland E, Krishnan N, Rönnholm A, Kalsum S, Puthia M, Mörgelin M, Davoudi M, Otrocka M, Alaridah N, Glegola-Madejska I, Sturegård E,

Schmidtchen A, Lerm M, Robertson BD, Godaly G. A novel derivative of the fungal antimicrobial peptide plectasin is active against *Mycobacterium tuberculosis*. Tuberculosis (Edinb). 2018;113:231-238. doi:10.1016/j.tube.2018.10.008.

40. Winkelman MJ. *Amanita muscaria*: Fly agaric history, mythology and pharmacology. J Psychedelic Stud. 2022;6(1):1-4. doi: 10.1556/2054.2022.00216.
41. Wu S, Chen X, Ren J, Liu P, Yan Q, Chen Z. Cuparene-type sesquiterpenes with neuroprotective activities from the edible mushroom *Flammulina filiformis*. Fitoterapia. 2024;179:106235. doi:10.1016/j.fitote.2024.106235.
42. Yakobi SH, Mkhize S, Pooe OJ. Screening of antimicrobial properties and bioactive compounds of Pleurotus ostreatus extracts against *Staphylococcus aureus*, *Escherichia coli*, and *Neisseria gonorrhoeae*. Biochem Res Int. 2023;2023:1777039. doi:10.1155/2023/1777039.
43. Yu EJ, Han SR, Kim KH, Park BR, Lim KO, Oh TJ. Antibacterial and antioxidant activity of *Pleurotus eryngii* extracts. Indian J Public Health Res Dev. 2018;9:2206. doi:10.5958/0976-5506.2018.02191.5.
44. Zhong Y, Tan P, Lin H, Huang Y, Zhang H, Li D, et al. A review of *Ganoderma lucidum* polysaccharide: preparations, structures, physicochemical properties and application. Foods. 2024;13(17):2665. doi:10.3390/foods13172665.
45. Zhu X, Xu S, Lu L, Wang S, Zhao Q, Li D, Li J, Zhao H, Xu B. Preparation, characterization, and *in vivo* evaluation of a polymorphic form of valnemulin hydrogen tartrate. J Vet Sci. 2019 Mar;20(2):e16. https://doi.org/10.4142/jvs.2019.20.e16
46. National Institute on Drug Abuse. Psilocybin (magic mushrooms) [Internet]. Bethesda (MD): National Institute on Drug Abuse; 2024 Jan 24. Available from: https://nida.nih.gov/research-topics/psilocybin-magic-mushrooms
47. World Health Organization. Antimicrobial resistance [Internet]. Geneva: WHO;. Available from: https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance
48. World Health Organization. Tuberculosis [Internet]. Geneva: WHO;. Available from: https://www.who.int/news-room/fact-sheets/detail/tuberculosis
49. Public Health Center of the Ministry of Health of Ukraine. Statistics of tuberculosis in Ukraine, March 2025 [Internet]. Kyiv: PHC; 2025 Mar 29. Available from: https://www.phc.org.ua/news/statistika-tuberkulozu-v-ukraini-berezen-2025-roku

Стаття надійшла до редакції 14.09.2025 р.