Wild and cultivated mushrooms as food, pharmaceutical and industrial products

Olena Stabnikova[1], Viktor Stabnikov[1], Octavio Paredes-López[2]

1 – National University of Food Technologies, Kyiv, Ukraine
2 – National Polytechnic Institute, Guanajuato, Mexico

Keywords:

Mushrooms
Food
Pharmaceutical
Industrial

Article history:

Received 22.09.2023
Received in revised form 18.01.2024
Accepted 29.03.2024

Corresponding author:

Olena Stabnikova
E-mail:
stabstab6@gmail.com

DOI: 10.24263/2304-974X-2024-13-1-4

Abstract

Introduction. Mushrooms have been consumed since earliest times and have been recognized for their attractive sensory and culinary attributes; besides, they contain high amounts of bioactive and health-promoting compounds. This review is devoted to wild edible mushrooms and their role in the life of modern man.

Materials and methods. Literature research using scientific publications on the topics related to wild mushrooms as a food resource, their applications in medicine and pharmaceuticals, as well as the methods for mushroom cultivation was conducted.

Results and discussion. Wild edible mushrooms have high nutritional value, contain high-quality proteins, fiber, essential fatty acids, vitamins, including D2, microelements, as well as valuable compounds such as polyphenols, terpenoids, sterols, while having a low energy value, which makes it possible to use them in cooking and in low-calorie diets. Wild edible mushrooms have various specific pharmaceutical properties that can be used in the treatment of various serious diseases. The gathering and use of wild edible mushrooms for food make a significant contribution to both the solution of the global food shortage crisis and economics of different countries around the world, and could be considered in some countries as new sources of income for local people. The increase of interest on mushroom consumption along human history at worldwide level has led to the development of basic and sophisticated techniques for their cultivation. Solid-state and submerged liquid fermentations are nowadays useful methods for cultivation of mushroom in a large-scale for production of volumes of biomass and of valuable specific bioactive metabolites. An interesting and unusual method to grow edible mushrooms of *Ustilago maydis*, which are considered a delicacy produced by the natural infection of the maize ears, is described.

Conclusions. The role that the mushroom kingdom plays in human life is extremely important and varied. In the near future, their role in local economies around the world and as raw materials for food and pharmaceutical products, including industrial cultivation, will be areas of greatest use.

Introduction

Mushrooms are considered to be among the most mysterious forms of life on our planet (Lincoff, 1981). Mushroom belonging to the phylum *Basidiomycota* is the fleshy fruiting body of a certain type of fungus, typically formed over the substrate used for fungi growth. Wild mushrooms have been recognized as a source of food and medicine from ancient times. Thus, it was proved that about 18,700 calendar years ago people ate mushrooms: spores of *Agaricales* and *Boletales* were found in a tooth plaque of a woman buried in the Upper Palaeolithic in northern Spain (Straus et al., 2015).

Legends and superstitions that existed among various peoples associated with mushrooms have come down (Bertelsen, 2013). The Egyptians considered mushrooms to be plants of immortality being a gift from the god Osiris and called them "the flesh of the gods" (Budge, 2017). According to the laws of ancient Egypt, only the pharaoh and his entourage could consume mushrooms, but common people were not allowed to even touch them. In Greek mythology, the growth of mushrooms came from lightning sent to earth by Zeus, as they appeared after thunderstorms. To the ancient Romans mushrooms were "the foods of the Gods" (Niksic et al., 2016), and mushrooms were included in the menu for special occasions (Rahi and Malik, 2016).

The images of mushrooms have been found in prehistoric cave paintings, the oldest of which, found in caves in the Sahara Desert (Tassili, Algeria) and in southern India, which were made by Prehistoric Early Gatherers in 9000-7000 B.P. (Before the Present) and in 1000 B.C. (Before Christ) – 100 A.C. (After Christ), respectively (Samorini, 2001). Depiction of a mushroom in shamanistic scene was found on Mount Bego, France dating at 1800 B.C. (Samorini, 2001).

Some mushrooms have been known for their hallucinogenic effects and early humans used them in spiritual rituals. Fly agaric mushroom (*Amanita muscaria*) has a hallucinogenic effect but can be poisonous to humans (Figure 1). Many legends tell that the Vikings consumed before the battle these mushrooms to induce frenzy and fearlessness and be less sensitive to pain. The native peoples in pre-Columbian Mesoamerican societies used hallucinogenic species of the *Psilocybe* genus in group ceremonies for religious communion (Carod-Artal, 2015). Numerous so-called 'mushroom stones' (sculptures) dating from 1000 – 500 years. B.C. were found in Mexico, Guatemala and Salvador testifying to the existence of mushroom cult in Mesoamerica.

Lingzhi, also known as reishi or *Ganoderma* is a mushroom tightly connected with Taoism. Taoist temples in ancient China were called "the abode of mushrooms", and Lingzhi, "spirits mushroom", used for a concentrated hallucinogenic decoction, was called "the mushroom of immortality". Some mushrooms possess toxicity; among the huge variety of existing mushrooms, about 100 species are poisonous to humans (Graeme, 2014; Li et al., 2021).

Mushrooms have an extremely varied size, shape and appearance; some of them are brightly colored, those belonging to *Phallus indusiatus* are wrapped in a transparent veil, and smell of the cap of Wood witch attracts flies and other insects (Figure 1).

For a long time, mushrooms were not grown, and they could only be collected from their natural habitats. And even today, only a small number of mushroom species are cultivated compared to the total number of edible species. In the modern world, there is an ever-increasing interest in mushrooms as a food product having certain health benefit properties. There are three main areas on the use of mushrooms, namely, wild edible, medicinal and commercially cultivated (Anusiya et al., 2021).

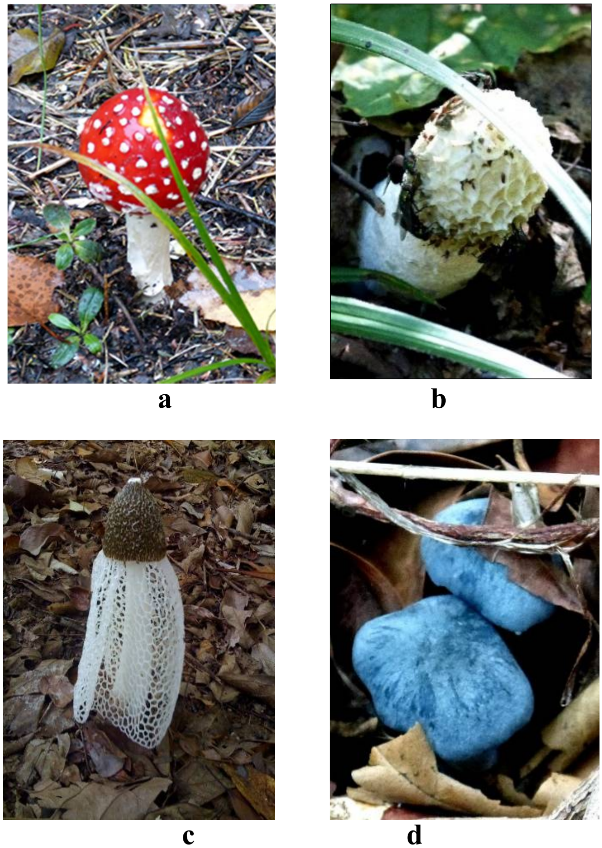

Figure 1. Variety of shapes and colors of mushrooms:
A, Fly agaric (*Amanita muscaria*); B, Wood witch (*Phallus duplicatus*);
C, Bamboo mushrooms (*Phallus indusiatus*); D, Blue mushroom in the tropical forest.

Wild mushrooms as food products

Wild edible mushrooms could serve as a source of ingredients for production of functional food. Mushrooms consist of the fruiting body (stalk, cap, and gills) and mycelium, a root-like structure. Gathering of wild mushrooms for using them for food has been done since ancient times. Fruit bodies of growing mushrooms make up a certain part of the diet of the poor in many rural areas around the world, and at the same time are a favorite delicacy of many gourmets. It was reported based on the current data over 100 countries that more than about 2,100 species of mushroom having different degrees of edibility exist in nature; however the number of them accepted as food does not exceed 25 (Barros et al., 2007; Pérez-Moreno et al., 2021; Zhang et al., 2013). The global market of wild edible fungi exceeded 1, 230,000 tons in 2017 estimated to be worth more than 5 billion USD (Pérez-Moreno et al., 2021). The harvesting of some wild mushrooms takes place on an especially large scale and has become now a really big business (Peintner et al., 2013). This is especially true for chanterelles (*Cantharellus cibarius*), morels (*Morchella esculenta*, *M. deliciosa* and *M. elata*), truffles (*Tuber melanosporum* and *Tuber magnatum*) and matsutake (*Tricholoma matsutake*) (Moore et al., 2020). Truffles, underground mushrooms, are especially appreciated by gourmets. In Europe, truffles are mainly collected in France and Italy. Previously, they were searched for with specially trained pigs, but now dogs are used for this purpose. Matsutake ("pine mushroom" in Japanese) has a unique taste and aroma and occupies a place in Japanese cuisine similar to the truffle in European cuisine. The price for these mushrooms is extremely high. The cost of truffles depends on season, weather factors (drought or rainfall) and of mushroom size; for example, the price of white truffles in 2022 was around 4,500 euros/kg (Trivelli Tartufi, 2023). A piece of matsutake, one of the most expensive mushrooms, which can only be harvested in the forest, their natural habitats, could be sold for more than 200 USD in the Tokyo market and its overall value is estimated as 4.6 to 7.7 billion USD annually (Moore et al., 2020). The annual world export market of collected chanterelles has been estimated at over 1.5 billion USD (Thorn et al., 2021; Watling, 1997).

It has been reported that the market of wild mushrooms is constantly increasing due to the decline of the traditional forest-based industries; gathering of this product in some countries are now considered as new sources of income (De Frutos Madrazo et al., 2012; Dejene et al., 2017; Román and Boa, 2006; Sileshi et al., 2023; Tibuhwa, 2013). The increased interest for forest mushrooms led to development of "mycosilviculture" aimed at improving productivity and profitability of forest stands, and consequently a better mushroom availability (Corona et al., 2016; Savoie and Largeteau, 2011; Tomao et al., 2017).

Composition of wild mushrooms. Species of wild mushrooms are diverse in taxonomic, ecological, and physiological features; they grow everywhere on a variety of flat and forest soils, and it is influenced, as expected, by local climatic conditions. Among the global mushroom industry, wild species account, according to their applications, for only 8%, while this number for cultivated and medicinal samples consists of 54 and 38%, respectively (Royse et al., 2017). Interestingly, edible wild mushrooms have a high nutritional value containing protein, fibers, essential fatty acids, vitamins, and trace minerals while having low energetic value and are cholesterol-free.

The composition of fruiting bodies of five species of the most popular wild edible mushrooms (Figure 2) are shown in Table 1.

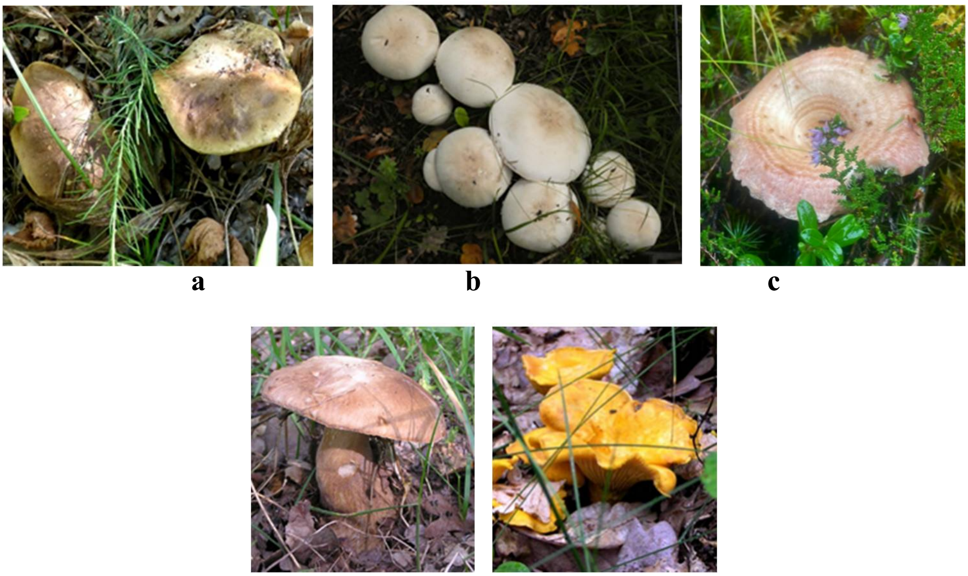

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Figure 2. The most popular wild edible mushrooms:
A, Slippery Jack (*Suillus luteus*); B, Horse mushroom (*Agaricus arvensis*); C, Saffron milk cap (*Lactarius deliciosus*); D, Porcini, (*Boletus edulis*); E, Chanterelle (*Cantharellus cibarius*).

Table 1

Composition of mushroom fruiting bodies and their energetic value

Mushroom species	**DM, %**	**g/100 g of dry matter (DM)**				**kcal/100 g DM**	**Reference**
		Protein	Carbohydrates	Fat	Ash		
Suillus granulatus (Portugal)	n.a.	14.8	73.5	3.7	8.0	387	Reis et al., 2014
S. granulatus (Serbia)	n.a.	7.9	81.4	0.3	10.4	360	Reis et al., 2014
Agaricus arvensis (Portugal)	5.1	56.3	37.5	2.7	3.5	400	Barros et al., 2007
A. bisporus (Portugal)	n.a.	80.9	8.3	0.9	9.9	370	Barros et al., 2008a
Lactarius deliciosus (Portugal)	10.0	29.8	62.9	2.2	5.1	389	Barros et al., 2007
L. deliciosus (China)	8.0	17.2	66.6	4.8	8.6	379	Xu et al., 2019
Boletus edulis (Greece)	12.4	27.2	62.1	2.8	6.3	n.a.	Ouzouni and Riganakos, 2007
B. edulis (Poland)	11.9	20.3	66.0	7.8	5.9	379	Jaworska et al., 2015
B. edulis (Chorvatia)	12.2	36.9	64.3	2.9	5.3	356	Beluhan and Ranogajec, 2011
Cantharellus cibarius (Portugal)	N/A	69.1	14.3	4.5	12.1	376	Barros et al., 2008a
Cantharellus cibarius (Portugal)	7.6	53.8	32.1	2.9	11.5	371	Barros et al., 2008b
C. cibarius (Greece)	17.4	21.6	66.1	2.9	9.4	n.a.	Ouzouni and Riganakos, 2007

n.a. – not applicable

Body of the mushroom contains high levels of water, 86 – 94 g/100 g, so the content of dry matter (DM) is very low. The range of the different compounds present in wild edible species growing in Central and Eastern Europe is extremely varied, in g/100 g DM: protein from 7.9 for *Suillus granulatus* (weeping bolete) to 56.3 for *Agaricus arvensis* (horse mushroom, snowball mushroom) and 80.9 for *A. bisp*orus (button mushroom); fat from 0.3 for *S. granulatus* to 11.5 for *Boletus edulis*; ash from 3.5 for *A. bisporus* to 11.5 for *Cantharellus cibarius* (chanterelle), and carbohydrates from 8.3 for *C. cibarius* to 81.4 for *S. granulatus*. *Boletus edulis* (king mushroom, penny bun, porcino or porcini), one of the most famous edible mushrooms in many countries, contain protein, 27.2; fat, 2.8, and ash, 6.3

(Ouzouni and Riganakos, 2007). It was found that wild species are even richer by protein and have lower fat content in comparison with cultivated ones (Barros et al., 2008). Low energy value, allowed to use mushrooms in low-calorie diets (Barros et al., 2007; 2008a, b; Beluhan and Ranogajec, 2011; Jaworska et al., 2015; Kalač, 2009; Ouzouni and Riganakos, 2007; Xu et al., 2019).

Phenolic acids in wild mushrooms. Wild edible mushrooms are a rich source of phenolic acids, which are known possess antioxidant and anti-inflammatory activities. p-Hydroxybenzoic acid and cinnamic acid are the main compounds present almost in all analyzed wild mushrooms (Table 2).

Table 2

Amount of phenolic acids in wild edible mushrooms, mg/100 g DW

Mushroom species	Protocatechuic acid	p-Hydroxy-benzoic acid	Vanillic acid	Sinapic acid	Cinnamic acid	p-Coumaric acid	Total amount	Reference
S. granulatus (Portugal)	n.a.	0.480	n.a.	n.a.	0.130	n.a.	0.590	Reis et al., 2014
S. granulatus (Serbia)	n.a.	0.130	n.a.	n.a.	0.030	n.a.	0.130	Reis et al., 2014
S. collinitus (Portugal)	0.528	1.414	n.a.	n.a.	0.134	n.d.	2.066	Vaz et al., 2011
S. mediterra-neensis (Portugal)	0.138	0.204	n.a.	n.a.	0.098	n.d.	0.440	Vaz et al., 2011
A. arvensis (Portugal)	n.d.	7.013	n.d.	n.a.	4.910	4.867	16.790	Barros et al., 2009
*A. bisporu*s (Portugal)	n.d.	2.559	n.d.	n.a.	0.872	n.d.	3.431	Barros et al., 2009
L. deliciosus (Portugal)	n.d.	2.266	n.d.	n.a.	1.497	n.d.	3.763	Barros et al., 2009
L. deliciosus (Poland)	0.137	n.d.	n.d.	1.429	0.406	n.a.	1.972	Muszyńska et al., 2013
L. deliciosus (Spain)	1.864	2.140	n.a.	n.a.	n.a	n.d	4.004	Palacios et al., 2011
L. aurantiacus (Portugal)	n.d.	n.d.	n.a.	n.a.	0.918	n.d.	0.918	Vaz et al., 2011
B. edulis (Poland)	0.750	0.194	n.d.	n.d.	n.d.	n.a.	0.944	Muszyńska et al., 2013
C. cibarius (Poland)	0.150	0.230	0.332	0.304	0.129	n.a.	1.149	Muszyńska et al., 2013
C. cibarius (Portugal)	n.d.	n.d.	n.d.	n.d.	1.497	n.a.	1.497	Barros et al., 2009

n.d.– not detected; n.a. – not applicable.

Fatty Acid in wild mushrooms. Lipids of mushrooms contain fatty acids, which are represented by saturated (SFA—without double bonds), monounsaturated (MUFA—with one double bond) and polyunsaturated fatty acids (PUFA—with two or more double bonds). The human body cannot synthesize PUFA, so the presence of them is recommended to be included in commonly used foods (Stabnikova and Paredes-López, 2023). Monounsaturated and polyunsaturated fatty acids are prevalent in mushroom fatty acid composition (Table 3).

Table 3

Fatty acid composition (percent) of the wild edible mushrooms

Mushroom species	Total SFA	Total MUFA	Total PUFA	Reference
S. granulatus	1.32	63.30	35.38	Ribeiro et al., 2009
A. bisporus	22.1	1.5	76.4	Barros et al., 2008a
B. edulis	14.5	40.9	44.6	Barros et al., 2008a
B. edulis	0.96	68.27	30.77	Ribeiro et al., 2009
C. cibarius	12.00	37.50	50.40	Barros et al., 2008a
C.cibarius	3.24	78.89	17.87	Ribeiro et al., 2009
L. deliciosus	22.13	48.37	29.49	Xu et al., 2019

SFA – saturated fatty acids; MUFA – monounsaturated fatty acids;
PUFA – polyunsaturated fatty acids.

The most abundant fatty acids in *Suillus granulatus*, % of total amount, were: oleic acid (C18:1, ω-9), 62.79 and linoleic acid (C18:2, ω-6), 35.35. The most abundant fatty acids in *Agaricus bisporus,* % of total amount, were: palmitic acid (C16:0), 9.97; stearic acid (C18:0), 4.08; linoleic acid (C18:2, ω-6), 75.72, and behenic acid (C22:0), 1.62 (Barros et al., 2008a). The most abundant fatty acids in for *Cantharellus cibarius,* % of total amount, were: palmitic acid (C16:0), 13.08; oleic acid (C18:1, ω-9), 10.78; linoleic acid (C18:2, ω-6), 53.59; α-linolenic acid (C18:3, ω-3), 0.10, and eicosenoic acid (C20:1), 27.98 (Barros et al., 2008a). The most abundant fatty acids in *Boletus edulis*, % of total amount, were: palmitic acid (C16:0), 10.03; oleic acid, (C18:1, ω-9), 39.72, and linoleic acid, (C18:2, ω-6), 44.32 (Barros et al., 2008a). For fifteen species of wild edible mushrooms belonging to the genus *Boletus* grown in Israel, it was determined that oleic acid (18:1, ω-9), 15-42%, linoleic acid (18:2, ω-6), 38–58%, and palmitic acid (16:0), 7–17% were the most abundant (Hanuš et al., 2008). The main fatty acids for *Lactarius deliciosus*, % of total amount, included: palmitic acid (C16:0), 5.17; stearic acid (C18:0), 16.96; oleic acid (C18:1, ω-9), 48.37; linoleic acid (C18:2, ω-6), 29.49 (Xu et al., 2019).

So, oleic, mono-unsaturated omega-9 fatty acid, and linoleic, polyunsaturated omega-6 fatty acid, were present in the highest amount in all mentioned above, wild mushrooms. This is consistent with the finding of Sande and co-authors (2019) who, based on reviewing the literature of *Agaricus bisporus*, *Pleurotus ostreatus*, and *Boletus edulis* mushroom species from different continents noted the predominant presence of the same fatty acids, but their quantitative composition varied significantly: linoleic acid ranges from 0.0–81.1%, oleic acid between 1.0 and 60.3%, and linolenic acid from 0.0–28.8%.

Vitamin D in wild mushrooms. It was shown that mushrooms are a good dietary source of vitamin D, which actively participates in regulation of calcium metabolism and needed to reduce the risk of osteomalacia in adults and rickets in children (Charoenngam et al., 2019). Recommended daily intake of this vitamin is 15 μg/day in Europe, USA, and Canada (Cardwell et al., 2018).

In wild mushrooms exposed to UV radiation, ergosterol present in the cell membrane is converted to D2, one of the forms of vitamin D. Bioavailability of vitamin D2 from mushrooms for humans was demonstrated by the results of clinical studies (Keegan et al., 2013; Mehrotra et al., 2014; Outila et al., 1999). The content of vitamin D2 in some wild mushrooms is shown in Table 4.

Table 4

Content of vitamin D2 in some wild edible mushrooms

Mushroom species	D2, µg/100 g FM	Reference
Agaricus bisporus (Finland)	0.21	Mattila et al., 1994
Agaricus sp. (wild) Denmark	1.50	Kristensen et al., 2012
Boletus edulis (Sweden)	58.7	Teichmann et al., 2007
Boletus edulis (Finland)	2.91	Mattila et al., 1994
Cantharellus cibarius (Finland)	12.80	Mattila et al., 1994
Cantharellus cibarius (Sweden)	10.7	Teichmann et al., 2007
Cantharellus tubaeformis (Sweden)	21.1	Teichmann et al., 2007

FM is fresh matter.

Mushrooms from genera *Cantharellus* have a high amount of vitamin D2 (ranging from 10.7 to 21.1 µg /100 g FM) that is preserved after culinary treatment. Thus, the content of vitamin D2 in canned *Cantharellus cibarius* was 12.1 µg/100 g FM (Teichmann et al., 2007). King mushroom *Boletus edulis* could be a source of vitamin D2, meanwhile the content of D2 in mushrooms from the genera *Agaricus* is low (Teichmann et al., 2007).

Biological active substances in wild mushrooms. Wild mushrooms possess antioxidant activity due to the presence of such bioactive substances as flavonoids, phenolic compounds, tocopherols, ascorbic acid and carotenoids (β-carotene and lycopene) (Table 5).

It should be mentioned that mushrooms also are rich with the vitamins B group such as B1 (thiamine), B2 (riboflavin), B3 (niacin), B5 (pantothenic acid), B6 (pyridoxine), B7 (biotin), B9 (folate), (Dimopoulou et al., 2022; Cağlarirmak, 2011; Muszyńska et al., 2017). Mushrooms usually contain small amounts of vitamin B12 (cobalamin), but relatively high levels of this vitamin was found in golden chanterelle (*Cantharellus cibarius*) from Germany, France and Bulgaria, 1.09 – 1.87 µg/100 g DM, meanwhile B12 in porcini mushrooms (*Boletus* spp.), parasol mushrooms (*Macrolepiota procera*), and black morels (*Morchella conica*) was absent or detected on low levels from 0.01 to 0.09 µg/100 g DM (Watanabe et al., 2012). Higher amounts of B12 were found in commercial shiitaki (*Lentinula edodes*) fruiting bodies, 5.61 µg/100 g DM (Watanabe et al., 2014).

Carbohydrates in wild mushrooms. Carbohydrates of mushrooms include mainly chitin, and also hemicellulose and glycogen. The presence of indigestible chitin apparently limits availability of the nutrients contained in mushrooms (Borthakur and Joshi, 2019) and causes the fact that people with diseases of the gastrointestinal tract are not recommended to consume mushrooms in significant quantities. However, chitin well absorbs toxins and heavy metals, removing them from the body during digestion. The active polysaccharides (β-glucans) contained in mushrooms strengthen the immune system and are considered as a health-promoting factor. Due to the presence in mushrooms carbohydrates such as hemicellulose, chitin, α- and β-glucans, xylans, mannans and galactans also serve as a prebiotic (Jayachandran et al., 2017). It is considered that 100 g of mushrooms supply from 9 to 40% of the daily recommended allowance of dietary fiber (Manzi et al., 2001).

Table 5

Total bioactive compounds of wild mushrooms

Mushroom species	**Content, mg/100g DW**			**Content, µg/100 g DW**			**Reference**
	Total phenols	**Flavonoids**	**Ascorbic acid**	**β-carotene**	**Lycopene**	**Total tocopherols**	
Suillus luteus (Poland)	876	n. a	n. a	n. a	n. a	n. a	Witkowska et al., 2011
Suillus luteus (Turkey)	506	n.a	8.2	n.a.	n.a.	n.a.	Keleş et al., 2011
A. arvensis (Portugal)	272	165	2	852	470	n.a.	Barros et al, 2008c
Agaricus bisporus (Portugal) wild On compost	853	367	n. a	n. a	n. a	n. a	Machado-Carvalho et al., 2023
Agaricus bisporus wild (Turkey)	402	n.a.	n.d.	n.a.	n.a,	n.a.	Keleş et al., 2011
Lactarius deliciosus (Poland)	429	n. a	n. a	n. a	n. a	n. a	Witkowska et al., 2011
Lactarius deliciosus (Turkey)	271	n.a,	≤ 20	n.a.	n.a.	n.a.	Keleş et al., 2011
Boletus edulis (Portugal)	503	175	n.d.	273	114	1065	Barros et al., 2008a
Boletus edulis (Poland)	1618	n. a	n. a	n. a	n. a	n. a	Witkowska et al., 2011
Boletus edulis (Poland)	446	32	22.1	1060	68.6	494	Jaworska et al., 2015
Boletus edulis (Portugal)	1096	161	n. a	n. a	n. a	n. a	Machado-Carvalho et al., 2023
Cantharellus cibarius (Portugal)	88	67	86	1356	506	1.8	Barros et al., 2008
Cantharellus cornucopioides (Portugal)	213	171	87	1277	513	187	Barros et al., 2008

n.d – not detected; n.a- not applicable.

Mineral elements in wild mushrooms. Usual content of major mineral elements in wild growing mushrooms is as follows, mg/100 g of dry matter: sodium, 10–40; potassium 2000–4000; calcium, 10–50; magnesium, 80–180; phosphorus, 500–1000; sulfur, 100–300 (Kalač, 2009). The accumulation of a wide variety of minor and trace elements in mushrooms is species- and site-dependent (Alaimo et al., 2019). Taking into account the ability of mushrooms to absorb heavy metals, especially mercury, lead, arsenic and cadmium, it should be noted that they can be collected only in noncontaminated places far from industrial areas (Nowakowski et al., 2021).

Other useful properties of wild mushrooms. Mushrooms do not contain cholesterol, and it has been even reported that they possess cholesterol lowering properties (Berger et al., 2004). It is generally recognized that mushrooms contain such valuable compounds as polyphenols, terpenoids, vitamins including D2, sterols, the unusual amino acid ergothioneine, β-glucans, which are responsible for their anti-inflammatory, antitumor, antiallergic, hepatoprotective, immunomodulating, antioxidant and antimicrobial activities (Kalaras et al., 2017; Lallawmsanga et al., 2016; Muszyńska et al., 2018; Patel and Goyal, 2012; Roncero-Ramos nd Delgado-Andrade, 2017).

It should be noted that although mushrooms of the same species grow under similar conditions, for example chanterelles grow in coniferous forests in mossy areas or in birch forests, but their chemical composition may differ depending on the place of growth, soil and climatic features of the area, and time of harvesting.

Popular species of wild edible mushrooms growing in European forests are shown in Figure 3.

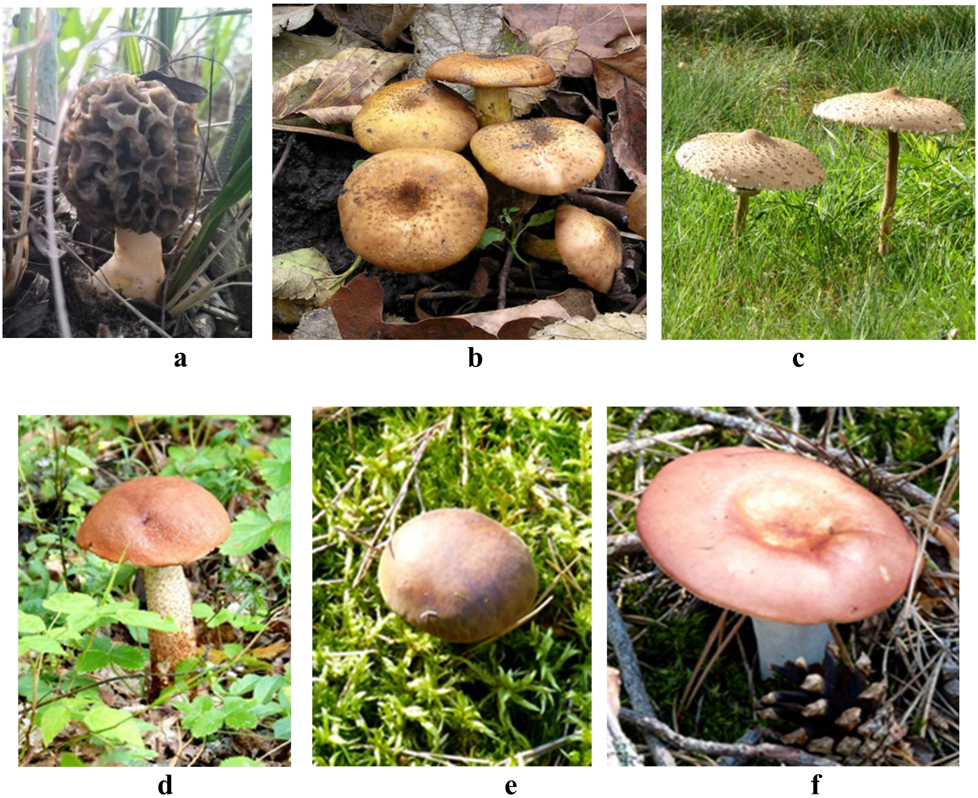

Figure 3. Popular European wild edible mushrooms:
A, Early morel (*Verpa bohemica*); B, Honey mushrooms (*Armillary mellea*);
C, Parasol mushroom (*Macrolepiota procera*); D, Aspen bolete (*Leccinum insigne*);
E, Bay bolete (*Imleria badia*); F, Emetic russula (*Russula rugulosa*);
G, Birch bolete (*Leccinum scabrum*).

Low sodium content, 10 – 40 mg/100 g, in mushrooms independent of their habitat and taxonomic position (Na in whole milk 40-60 mg/100 g, and in meat products 1000-2200 mg/100 g) (Vetter, 2003) makes them advisable supplement to meat to decrease sodium intake (Guinard et al., 2016). Moreover, due to mushroom savory flavor their addition to any dish allows to diminish sodium content in the diet. The substitution of 80% of the meat with ground champignons (*Agaricus bisporus*) in the beef taco blend did enhance its overall flavor and allowed to reduce salt content by 25% (Myrdal Miller et al., 2014).

Use of wild mushrooms in food products. It is considered that mushrooms possess a unique taste called umami (Japanese word means "essence of deliciousness"), the fifth taste combining sweet, sour, salty and bitter, which is created by monosodium glutamate-like amino acids and 5'-nucleotides (Bernas, 2017; Zhang et al., 2013). Thus, it was estimated that mushrooms *Agaricus bisporus* contain about 370 mg of monosodium glutamate per 100 g of DM (Bernas, 2017). Therefore, by adding mushrooms to food products, three goals are achieved: increasing the nutritional value, giving the product an exquisite taste, and a certain medical positive effect. However, the cases of food allergy caused by consumption of different mushrooms have been reported (Ito et al., 2020; Kobayashi et al., 2019) and it is considered that around 1–3% of human population have allergy to mushrooms (Anusiya et al., 2021).

The use of edible wild mushrooms for food preparation in catering establishments, food for individual consumption is well known. But there is experience in the use of wild mushrooms in industrial food production. For example, *Cantharellus cibarius* grows from June to October in pine, birch, oak and hornbeam forests and has been used for food preparation in several European countries, Asia, America, and Africa. Only in Europe chanterelle mushrooms are collected for about 188,000 tons per year (Bulam et al., 2021). These mushrooms are used to supplement different dishes like omelets, soups, risotto, pizza, meat and fish dishes. It is a commercially important mushroom, which is present in the world market in fresh, dried, frozen and pickled state.

There are many special dishes from different countries using wild mushrooms. Examples of such dishes popular in European countries can be risotto made with wild mushrooms, a famous Italian dish; Slovak soup "kapustnica", prepared from sauerkraut, smoked meat, sausage, prunes, and mushrooms; Polish bigos (type of stew) made from sauerkraut, different meats, sausage, prune and dried or pickled wild mushrooms (Procházka et al., 2023; Weichselbaum et al., 2009). Fried mushrooms with onions, soup added with mushrooms, mushroom sauces are very popular dishes among Ukrainian population living in wooded areas (Luczaj et al., 2015), and application of wild mushrooms in different food products are appreciated in Lithuania and Germany.

Application of wild mushrooms in preparation of food products not only increases their biological value, but also serves to enhance their sensory properties like aroma and taste, and expands the shelf life of the final products. *Cantharellus cibarius* and *Boletus edulis* decoctions possess antioxidative and antimicrobial activity, and authors proposed to use them instead of the commercial antioxidants in preparation of frankfurters (Novakovic et al., 2019; 2020). Frankfurter sausages prepared with addition of the decoction of the dry powdered mushrooms improve odor, taste, and overall quality of finished products and increase the shelf life under chilled storage due to reducing lipid oxidation several times compared with control.

Due to the popularity of mushrooms worldwide, it may be of interest to note that for a long time hallucinogenic mushrooms were sold in the streets of Amsterdam; but a ban on their sale was introduced on December 1, 2008 (Figure 4).


a **b**

c

Figure 4. Hallucinogenic mushrooms in the streets of Amsterdam.

Wild mushrooms as pharmaceutical products

Wild edible mushrooms as well as cultivated ones possess different pharmaceutical properties including antidiabetic, antiallergic, antioxidative, antiviral, antibacterial, antifungal, immunomodulating, antidepressive, osteoprotective, nephroprotective, hypotensive and hepatoprotective activities and are used in the production of different pharmaceuticals (Anusiya et al., 2021; Thakur and Singh, 2013; Venturella et al., 2021). According to Gargano et al. (2017) mushrooms have more than 130 medicinal functions including also radical scavenging, cardiovascular, cholesterol-lowering, and detoxicative; drugs from mushrooms can be used as s painkillers and analgesics, as well as for prevention of immune disorders and improve quality of life in patients with various types of cancers or who are going under chemotherapy, patients with hepatitis B, C, and D and others. It is also suggested that bioactive compounds in mushrooms have shown neuroprotective effects on Alzheimer disease (Li et al., 2023). However, the pharmacological properties of medicinal mushrooms are studied mainly in *vitro* assays or in *vivo* using animal models, and there are only few clinical trials in humans showing positive effect of orally administered mushroom consumption on health state. So, we have focused only on proven cases of mushroom health benefits for humans. Crude extracts of the whole mushroom fruiting bodies or mycelia and isolated partially purified bioactive substances, for instance lentinan or polysaccharides, are more often used in medical studies (Table 5).

Table 5

Results of clinical trials of mushroom application for medical purposes

Mushroom	Preparation	Effect	Treatment of	Reference
Agaricus blazei	Extract	Reduces of chemotherapy-associated side effects	Gynecological cancer patients undergoing chemotherapy	Ahn et al., 2004
Agaricus sylvaticus	Dried extract	Improves of hematological and immunological parameters, reduce glycemic level	Postsurgical patients with colorectal cancer	Fortes et al., 2009
Agaricus sylvaticus	Dried extract	Increases in the immunity of patients	Patients with colorectal cancer	Fortes et al., 2009
Agaricus sylvaticus	Dried extract	Reduces of chemotherapy-associated side effects	Breast cancer patients undergoing chemotherapy	Valadares et al., 2013
Agaricus blazei	Encapsulated extract from dried mushrooms	Improves insulin resistance	Patients with type 2 diabetes	Hsu et al., 2007
Inonotus obliquus	Extract Befungin	Psoriasis rashes disappeared or weakened. Improves of gastrointestinal tract state	Patients with psoriasis	Frost, 2016
Inonotus obliquus	Extract Befungin	Reduces pain caused by peptic ulcers	Patients with peptic ulcers	Frost, 2016
Ganoderma lucidum	*Ganopoly®, 1880 mg, 3 times daily, 12 weeks	Enhances the immune responses	Patients with advance-stage cancer	Gao et al., 2003a
Ganoderma lucidum	Ganopoly®, 600 mg, 3 times daily, 12 weeks	Enhances the immune responses	Patients with advanced lung cancer	Gao et al., 2003b
Ganoderma lucidum	Spore powder, 1000 mg t3 times daily, for 4 weeks	Reduces cancer-related fatigue and enhances quality of life	Patients with breast cancer undergoing endocrine therapy.	Zhao et al., 2012

Mushroom	Preparation	Effect	Treatment of	Reference
Ganoderma lucidum	Rokkaku Reishi, 3 packs daily, 6 months	No significant anticancer effects	Patients with prostate cancer	Yoshimura et al., 2010
Ganoderma lucidum	Ganopoly®, treatment with 1800 mg, 3 times daily, 8 weeks	Improves of neurasthenia symptoms	Patients with neurasthenia	Tang et al., 2005
Ganoderma lucidum	Ganopoly®, 1800 mg, 3 times daily, 12 weeks	Lowers blood glucose concentrations	Patients with type 2 diabetes mellitus	Gao et al., 2004a
Ganoderma lucidum	Ganopoly®, mushroom polysaccharides	Decreases blood pressure, serum cholesterol levels	Patients with coronary heart disease	Gao et al., 2004b
Ganoderma lucidum	Lingzhi product, 1.44 g daily for 12 weeks	Lowers plasma insulin, normal plasma glucose levels	Patients with mild hypertension and/or hyperlipidemia	Chu et al., 2012
Hericium erinaceus	Mushroom powder	Improves cognitive abilities	Patients mild cognitive impairment	Mori et al., 2009
Lentinula edodes	Lentinan	Survival time extension	Patients with stomach tumors	Oba et al., 2009
Lentinula edodes	Dried mycelia extract, 1800 mg/day for 12 weeks	Decreases the adverse effects from chemotherapy	Patients with advanced cancer	Okuno and Uno, 2011
Antrodia cinnamomea	Aqueous extract, 20 ml daily, 30 days	Improves quality of sleep.	Patients with advanced cancer	Tsai et al., 2016
Poria cocos	Polysaccharidum of *Poria cocos* oral solution	Immune-therapeutics action	Patients with cancers, hepatitis and other diseases	Li et al., 2019
Poria cocos	Preparations from *Poria cocos*	Reduces fasting blood glucose	Patients with type 2 diabetes mellitus	Di et al., 2022
Grifola frondose	Maitake liquid extract 5-7 mg/kg, 2 times daily, 3 weeks	Increases immune activity	Patients with breast cancer	Deng et al., 2009

*Ganopoly®, mushroom polysaccharides

It was reported that such species of mushrooms with anticancer properties as *Lentinula edodes* (22.2% from total studies), *Coriolus versicolor*, and *Ganoderma lucidum* (both 13.9%), followed by *Agaricus bisporus* (*A. blazei* and *A. sylvaticus*) and *Grifola frondosa* (both 11.1%) are more often used in the clinic studies (Panda et al., 2022). Among mushrooms with pharmacological activity there are such species as *Agaricus blazei* (royal sun Agaricus), *Inonotus obliquus* (chaga), and *Ganoderma lucidum* (reishi) (Frost, 2016). These mushrooms are proposed to be used as antitumor agents and immunomodulators (El Enshasy and Hatti-Kaul 2013; Gariboldi et al., 2023).

Agaricus mushroom preparations were studied in clinical trials and it was shown that they could be useful for treatment of patients with cancer to diminish adverse chemotherapy-associated side effects (Ahn et al., 2004; Valadares et al., 2013), and improve health status of patients with colorectal cancer (Fortes et al., 2008; 2009). *Agaricus blazei*, native to Brazil, with a popular name as *Cogumelo do Sol* (sSun mushroom), or Himematsutake in Japan, is one of the more studied medicinal mushrooms. It was shown in randomized, blind, placebo-controlled clinical trials that preparation from *A. blazei* reduced chemotherapy-associated side effects by increasing appetite and emotional stability and diminishing alopecia and general weakness in gynecological cancer patients (Ahn et al., 2004). Dried extract of *A. sylvaticus* increased the immunity of patients with colorectal cancer (Fortes et al., 2008) and improved health status of postsurgical patients with colorectal cancer (Fortes et al., 2009); dietary supplementation with this mushroom (scaly wood mushroom) in form of dried extract reduced adverse side-effects of anticancer drugs improving gastrointestinal functions in patients with breast cancer treated with chemotherapy or radiotherapy (Valadares et al., 2013). Encapsulated extract from dried mushrooms *Agaricus blazei* increased insulin resistance in patients with type 2 diabetes (Hsu et al., 2007).

Inonotus obliquus (chaga, tinder fungus), is a black-brown mushroom that grows on damaged areas of deciduous trees more often on birches and less often on alder, ash, maple, rowan, beech, and elm, but only mushroom grown on birch has useful properties. This mushroom has been used in folk medicine from ancient times. Hippocrates described in the Hippocratic Corpus how to use infusions of this mushroom to wash wounds. And it was published in literature that Vladimir Monomakh, Grand prince of Kyiv, used this mushroom to treat himself for a lip tumor back in the 12th century (Szychowski et al., 2021). There are evidences that the fruiting bodies of *I. obliquus* have been employed in folk medicine in Eastern Europe in the 16 century (Lindequist et al., 2005) and has been used in the treatment of cardiovascular disease, gastrointestinal cancer, and diabetes mellitus until now (Duru et al., 2019).

Extracts from *I. obliquus* contain different biological active substances such as polysaccharides, polyphenols, triterpenoids, melanin, which have anticancer, anti-inflammatory, antiviral, antiparasitic, antioxidant, immunomodulatory, hypoglycemic, hypolipidemic, hepatoprotective, antiviral, hypolipidemic and immunomodulatory activities, and have at the same time the therapeutic potential to counteract the progression of cancer and diabetes (Lu et al., 2021; Szychowski et al., 2020). However, until present there are only few clinical studies confirming the effectiveness of the use of this fungus for medical purposes. There are reports of two clinical trials made in Russia in 1973-1981 (Frost, 2016). It was shown that application of commercially produced extract from chaga “Befungin” helps to normalize the health state of patients with psoriasis or peptic ulcers (Table 5). However, in case of peptic ulcers pain, which was relieved by taking the extract, returned to its previous level after stopping the intake.

Meanwhile, chaga mushrooms are widely used in pharmaceuticals. Despite the lack of controlled studies evaluating the safety of *I. obliquus* preparations from it, like many mushroom supplements, are produced mainly based on the experience of their long-term traditional use (Frost, 2016). The global market for chaga mushroom-based products is estimated at $ 25.8 billion USD in the year 2022, and it will probably reach $ 62.8 billion by 2030 (Report, 2013).

It should be noted that chaga is widely consumed not only as pharmaceutical, but also as herbal tea, syrup, bath agents, or concentrate (Duru et al., 2019). There are many reports of chaga beneficial health effects, but on the contrary there are some cases warning about the need to be careful when using chaga preparations as a pharmaceutical (Lee et al., 2020).

Ganoderma lucidum, wood-degrading basidiomycetes that can be found all over the world, is an edible medicinal mushroom known as Ling Zhi (the mushroom of immortality) in China and Korea, and reishi (the mushroom of spirituality) or Mannentake (10,000-year-old mushroom) in Japan. It has been known from ancient times in folk medicine of China, Japan and other Asian countries to treat stomach diseases, arthritis, and asthma. Studies conducted *in vitro* and *in vivo* showed its anti-inflammatory, antidiabetic, antiviral, and antibacterial activity and various other health benefits (Andrejč et al., 2022). At present, *Ganoderma lucidum* is one of the best studied species of medicinal mushroom. Description of reishi is included in the American Herbal Pharmacopoeia (AHP), and this mushroom is regulated as a dietary supplement in the United States (AHP, 2006). *G. lucidum* is included in the Pharmacopoeia of the People's Republic of China (2000) and approved for the treatment of dizziness, insomnia, palpitations, shortness of breath, cough and asthma (AHP, 2006).

G. lucidum contain about 400 different bioactive compounds (Ahmad, 2018), meanwhile triterpenes, polysaccharides, and peptidoglycans are three major groups of pharmacologically active constituents, which are present in different amounts in the fruiting bodies, mycelium and spores of reishi (Boh et al., 2007; Chan et al., 2021; Ferreira et al., 2015; Martínez-Montemayor et al., 2019). Preclinical studies showed that polysaccharides of this mushroom possess anti-tumor activity due to immunostimulating effects. Clinical study on humans indicated enhanced immune responses in advanced-stage cancer patients treated with 1,880 mg Ganopoly®, the polysaccharide fraction extracted from *G. lucidum*, three times daily for 12 weeks (Guo et al., 2003a). The immunomodulating effects of Ganopoly® taken 600 mg three times daily for 12 weeks by patients with advanced lung cancer was confirmed in a randomized double-blind, placebo-controlled clinical trial (Gao et al., 2003b). The authors concluded that Ganopoly® may have an adjunct role in the treatment of patients with advanced lung cancer. The clinic study showed that patients with breast cancer undergoing endocrine therapy who took spore powder of *G. lucidum* 1000 mg three times a day for 4 weeks became less anxious and depressed than those from the control group who received placebo (Zhao et al., 2012). A randomized, double-blind and placebo-controlled study of the efficiency and safety of Ganopoly[a] in Chinese patients with neurasthenia showed the improvement of neurasthenia symptoms after 8 weeks treatment with 1800 mg three times a day orally (Tang et al., 2005). It was shown in the clinic study that patients with confirmed type 2 diabetes mellitus after receiving exactly the same treatment had lower blood glucose concentrations than those in the placebo group (Gao et al., 2004a). The double-blind, randomized clinical trials showed a decrease in blood pressure and serum cholesterol levels in patients with confirmed coronary heart disease receiving extracted *G. lucidum* polysaccharides (Ganopoly) for 12 weeks (Gao et al., 2004b).

Currently, a great diversity of commercial *G. lucidum* products are available in forms of powders, dietary supplements, and tea (Chan et al., 2021; Wachtel-Galor et al., 2011). The world trade market value of *G. lucidum* and its derivative products is estimated approximately 4 billion USD and includes over 100 brands (El Sheikha, 2022). Dietary supplements containing reishi or substances from this mushroom could be used to support conventional medicine, as it was demonstrated in various clinical trials, to treat different diseases including cancer. However, further studies for confirmation efficiency and safety of reishi use in medicine should be conducted.

Poria cocos (wolf or fuling), an edible mushroom, which is found all over the world, growing on the dead bark and roots of diverse species of Pinus trees (Li et al., 2019). It has been used as traditional Chinese medicine for more than two thousand years to treat a wide range of human diseases. The most active substance in *Poria cocos* is its polysaccharide fraction, which consists of up to 84% of dried sclerotium weight. Pharmacological effects of *P. cocus* polysaccharides were intensively studied in recent years and as a result a medicine preparation "Polysaccharidum of *Poria cocos* oral solution" was developed and received approval as a drug by Chinese Food and Drug Administration in 2015 (Li et al., 2019). This drug could be used as immune-therapeutics to treat patients with different types of cancers, hepatitis and other diseases, alone or combined with chemo- or radiation therapy for cancer treatment. It was also shown in 73 randomized clinical trials that including of *Poria cocos* to hypoglycemic agent-treatments patients with type 2 diabetes mellitus could benefit reducing their fasting blood glucose (Di et al., 2022). Authors suggested that additional, deeper and careful studies are pending.

Other mushrooms with pharmaceutical properties undergoing clinical trials include *Hericium erinaceus* and *Antrodia cinnamomea*. *H. erinaceus* (Lion's mane mushrooms, yamabushitake) can be used for treatment of people with cognitive impairment. Terpenes and polysaccharides from this species stimulate the growth and differentiation of nerve cells and perform a protective function against exposure to oxidative stress. A double-blind, placebo-controlled clinical trial performed on 50- to 80-year-old Japanese men and women with mild cognitive impairment showed that intake of 250 mg tablets with 96% mushroom powder, three times a day, for 16 weeks improved patient's cognitive abilities (Mori et al., 2009). *A. cinnamomea* or *A. camphorata* is a very rare forest mushroom native to Taiwan that has been used as a traditional medicine for treatment of various human diseases including several types of tumor. However, human clinical trials to study the efficiency of *A. cinnamomea* as medicine are extremely limited. Advanced cancer patients receiving chemotherapy were administered with placebo or 20 mL of a mushroom aqueous extract daily for 30 days in a double-blind, randomized clinical study (Tsai et al., 2016). There was no improvement in the outcome of patients, except that the patients taken mushroom extract showed significantly better quality of sleep.

In another clinical study it was found the incidence decrease of adverse effects from chemotherapy among patients with advanced cancer who received orally dried *Lentinula edodes* mycelia extract, 1800 mg/day for 12 weeks (Okuno and Uno, 2011).

Among other medical mushrooms *Grifola frondosa* (hen-of-the-woods or maitake) is cited which an edible species is growing at the base of oaks or maples in Asia, Europe, and North America. Polysaccharides of its fruiting body and mycelium includes β-glucans and heteroglycans, and extracts of this mushroom demonstrated antitumor and immunomodulatory effects in preclinical studies. An increase in immune activity was observed in patients with breast cancer who took maitake liquid extract 5-7 mg/kg orally twice a day for 3 weeks (Deng et al., 2009).

Mushrooms contain many biologically active compounds, and a lot of modern studies are devoted to the isolation, study of properties and the possibility of using such substances in medicine, and they accounts for not less than 130 medical functions (Gargano et al., 2017). Polysaccharides, among these compounds, play outstanding functions with antitumor and immunomodulating activities which have been proven in clinical studies. It was demonstrated, for instance, for purified β-glucan lentinan, isolated from Lentinula edodes (shiitake mushroom), its successful application in the combined treatment of cancer diseases in Japan. It was shown, in randomized controlled clinical trials, that advanced gastric cancer patients treated with chemotherapy and lentinan had a much longer survival time compared to patients treated only with chemotherapy (Oba et al., 2009).

A serious drawback in the use of mushrooms for medical purposes is the lack of regulations, standards and protocols for their certified elaboration production and strict testing of mushroom products. This may be the main reason why commercial mushroom products change in composition and consequently in effectivity; even the active components of many commercial mushroom products have not yet been identified (Wasser, 2010, 2011). The latter item is one of the challenges for a more efficient and safety use of mushrooms in medicine.

On the other hand, more and more attention has been recently paid for studying the potential use of mushrooms to prevent Alzheimer's disease (AD) or slow down its symptoms in patients who have been already suffering from AD (Li et al., 2023; Silva et al., 2023). A lot of clinical trials have shown that dietary factors are extremely important in treating and preventing Alzheimer's disease (Bello-Corral et al., 2021; Stefaniak et al., 2022; Yusufov et al., 2017). Results of 10, out of 12, clinical studies demonstrated a protective effect of the Mediterranean plant-based diet on the risk of developing AD. It is believed that to reduce the risk factor for developing this disease, the diet should contain substances with neuroprotective properties, such as antioxidants, B vitamins and polyunsaturated fatty acids, which are present in mushrooms. In addition, these species contain a large number of biologically active compounds involved in mechanisms associated with AD including the potent antioxidants ergothioneine and glutathione as well as vitamin D, which may have neuroprotective properties. In people with mild cognitive impairment being potentially vulnerable to dementia reduced levels of ergothioneine, an unusual thio-histidine betaine amino acid, have been observed (Cheah et al., 2016). Ergothioneine is contained in mushroom fruiting bodies, where it is typically the main antioxidant; it has been found and quantified in various wild and cultivated mushrooms. The highest amounts of ergothioneine is reported in *Pleurotus* ostreatus (oyster), 2.59 mg/g DM, but it was found, mg/g DM, in *Lentinula edodes* (shiitake), 1.98; *Grifola frondosa* (maitake), 1.13; *Agaricus bisporus* (white button), 0.21 (Dubost et al., 2007); *Ganoderma lucidum* (reishi), 0.56; Hericium erinaceus (lion's mane mushroom), 1.12; *Boletus edulis* (porcini), 7.27; *Cantharellus cibarius* (chanterelle), 0.20; and *Morchella esculenta* (morel), 0.47 (Kalaras et al., 2017). In brief, it is considered that increased ergothioneine intake including mushrooms in the diet might possibly promote cognitive health (Feng et al., 2019).

Most studies regarding certain substances found in mushrooms were carried out in *vitro* and on animals, but there are also results from clinical studies on humans. For example, *Termitomyces* species, the termite mushrooms, contain cerebrosides, which are known to have an important role in the treatment of neurodegenerative disorders including AD (Paloi et al., 2023). Erinacine A, cyathin diterpenoid, a compound present in *Hericium erinaceus* (lion's mane mushroom) was evaluated in clinical trials to relieve AD symptoms and showed neurotrophic and neuroprotective activities (Li et al., 2020).

There are some clinical trials that prove beneficial role of mushroom consumption in improving cognitive performance. The cohort study involving 13,230 elderly Japanese people aged over 65 years showed that frequent consumption of mushrooms (3 times per week or more) reduced by 19% the risk of incident dementia (Zhang et al., 2017). The same finding that mushroom consumption may serve as a preventive measure to slow down neurodegeneration with aging was made by Singaporean researchers, who studied for more than 6 years the association between mushroom consumption and mild cognitive impairment based on data from 663 participants aged 60 years and older (Feng et al., 2019). An analysis of data from U.S. people over 60 years of age found that mushroom consumption is associated with cognitive performance, and if it is consumed in large amounts may reduce the risk of cognitive decline (Ba et al., 2022). Thus, regular intake of mushrooms is a way to potentially reduce the risk of neurodegenerative disorders.

Wild mushrooms as industrial products

Industrial cultivated edible mushrooms are very popular as food products (Rangel-Vargas et al., 2021) widely used for preparation of medicinal drugs (Valverde et al., 2015), and constantly increasing all over the world. Thus, world production of mushrooms has increased more than 30-fold since 1978 (Royse et al., 2017). Total production of mushrooms and truffles worldwide from 2012 to 2021 augmented from 31.78 to 44.21 million metric tons (Statista, 2023); China is a leading country producing about 75% of the word's mushrooms and is the world's largest producer of *Flammulina velutipes* (Royse et al., 2017). The most cultivated edible mushroom genera are *Lentinula* which covers about 22% of the world's production followed by *Pleurotus*, 19% of the world's output; *Auricularia*, 18%; *Agaricus*, 15%; *Flammulina*, 11%; *Volvariella*, 5%; and others, 10% (Royse et al., 2017) (Figure 5).

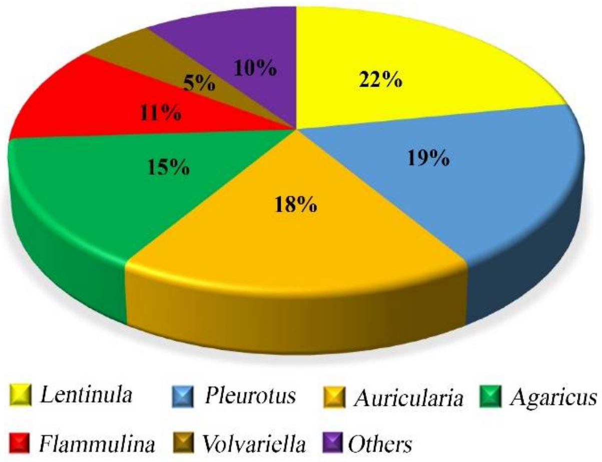

Figure 5. Cultivated mushrooms in percentage of total world's production (Adapted from Royse et al., 2017).

Pleurotus ostreatus (oyster mushroom), *Agaricus campestris*, and *Agaricus bisporus* (button mushroom) are cultivated all over the world, while *Lentinula edodes* (former *Lentinus edodes*) (shiitake), *Auricularia auricula* (wood-ear or tree ear), *Volvariella volvacea* (edible straw mushroom), *Flammulina velutipes* (winter mushroom) and *Ganoderma lucidum* (red reishi) are cultivated mainly in Asia (Stabnikova et al., 2008). Nowadays the mushroom production on a large scale is going in a form of so called solid state fermentation. However, there are two traditional methods, which are still used to harvest mushrooms: (a) cultivation on wood logs and (b) on compost.

Traditional methods used for mushroom cultivation. According to Japanese and Chinese traditions, *Lentinula edodes* (shiitake) was grown on shii (*Castanopsis cuspidata*) logs until the mid-1980s. Growth of shiitake on trees requires from one to two years before the first crop of fruiting bodies could be harvested. It is possible to expedite the growth of shiitake by growing the mushrooms aseptically in plastic bags or in trays on sterilized substrate containing saw dust, bagasse, straw, paper chips and supplemented with nutrients such as starch, yeast, sugars and protein (Figure 6a). Application of this method allows their harvesting in three-four months after inoculation; the residual compost could be used as a soil fertilizer (Stabnikova et al., 2008).

The composition of medium for shiitake cultivation could be different, but the basis of the substrate should be hardwood chips and sawdust and/or cereal straw. To increase the nutritional value, medium is supplemented with bran or grain, straw of cereals, waste from the food industry and agriculture. 2-3 mm is an optimal particle size of sawdust and shavings of hardwood trees, and cereal straw is crushed to a size of 1-2 cm. Chalk or gypsum is added to improve the physical properties of the substrate. Cultivation is carried out in special chambers with the maintenance of desirable microclimate under sterile conditions or in conditions of a high degree of purity. Under the cited conditions, a yield of fruiting bodies from 15 to 30-50% from the weight of used substrate may be obtained.

Pleurotus (oyster mushroom) are much easily cultivated and the corresponding costs are lower compared to others mushroom species because these mushrooms have a shortest time to produce fruit bodies; additionally they can be grown using various lignocellulosic agricultural wastes due to their ability to produce enzyme laccase, which plays a key role in lignin degradation (Li et al., 2022). Using different waste products as substrate for cultivation of oyster mushroom species (*Pleurotus ostreatus, P. cystidiosus, P. pulmonarius*) allows to reduce their price to a reasonable level. It was reported that oyster mushrooms can be grown on sawdust, wood chips, cereal straw, banana leaves, peanut hull, corn leaves, wheat and rice straw, mango fruits and seeds, sugarcane leaves, hazelnut branches and husk, rice husk, spent coffee grounds, coffee pulp, grass, weed plants, olive cake, tomato tuff, pine needles, and cotton wastes (Akcay et al., 2023; Das et al., 2007; Hernández et al., 2003; Jatwa et al., 2016; Li et al., 2022; Raman et al., 2020). For instance, lignocellulosic biomass mixture from grounded leaves of date palms (*Phoenix dactylifera*), wheat straw, saw dust, and boobialla (*Myoporum serratum*) supplemented with wheat bran and corn meal at 5% of the substrate dry weight and gypsum, 5% (Alananbeh et al., 2014). Oyster cultivation is conducted in plastic bags (Figure 6b) or trays.

Different species of *Pleurotus* can grow under different temperature conditions using pasteurized composed substrate or sterile non-composted one, meanwhile their fruiting bodies are relatively rarely exposed to diseases or pests. However, *Pleurotus* fruit bodies have short life that makes them less competitive than *Agaricus bisporus* and *Lentinula edodes* (shiitake) (Raman et al., 2020).

a b

Figure 6. Shiitake (A) and oysters (B) cultivation in plastic bags

After harvesting of oyster mushroom fruiting bodies, “spent compost” could be used as soil conditioner to enhance soil structure; biofertilizer; animal feed due to enrichment composting material with protein by mushroom mycelium, or to use in bioremediation of soil polluted with toxic organic substances (Moore et al., 2020; Sadiq et al., 2019). Because *Pleurotus* has the ability for easy accumulation of heavy metals, only waste free from this contaminant could be used in mushroom production.

Auricularia auricular has different common names such as black fungus due to its dark brown to black color and wood ear or ear mushroom because of its shape. In nature this mushroom grows mainly on deciduous older trees or dead and decaying branches. It is currently the third most produced mushroom in the world and is widely cultivated in Asian countries for food and medicinal applications. China is a major producer of *A. auricular,* which accounts for more than 90% of the total global production and amounted 7 018 million tons in 2019 (Hao et al., 2022; Zhao et al., 2019).

This fungus possesses cellulases, xylanase, laccase and polyphenol oxidase enzymatic activity, so it is able to decompose lignin and cellulose and can be grown on lignin containing agricultural wastes. So, methods of its cultivation using compost to produce fruit bodies for food is similar to *Pleurotus ostreatus*. Major advantage is that cultivation of *A. auricular* could be done using submerged fermentation on simple liquid media for further isolation of medicinal valuable substances (Sun et al., 2016).

Cultivation of wild mushrooms in Europe was started in the 1600s when growers in Paris grew species known as *Agaricus bisporus* in fields, but the European mushroom industry started in the limestone caves beneath Paris at the end of the nineteenth century. This underground mushroom cultivation method has been used until our days.

Cultivation of mushrooms includes two major steps: preparation of the compost or solid medium and mycelium growth until fructification. For production of compost or medium for mushrooms cultivation, different organic and lignocellulosic materials can be used, such as wood chips, sawdust, hay, maize waste, paddy straw, cassava bagasse, waste paper, cotton seed hulls, water hyacinth, apple pomace, grape pomace oil palm bunch, husk rice, banana leaves cheese whey, horse manure, chicken manure, and others (Ivanov et al., 2021; Moore et al., 2020; Stabnikova et al., 2008).

Button mushroom*s A. bisporus* is one of the most cultivated species in the world, and it is the dominant fungus cultivated in Europe. In the USA, about 98% of the mushroom production comes from button mushrooms. The fruit bodies of white button of this mushroom are produced in large amounts for human consumption on a medium consisting of wheat straw, straw-bedded horse manure, chicken manure and gypsum (Straatsma et al., 2000). The materials are mixed, the ingredients are wetted, and composted for 8–9 days while temperatures will rise to 80°C during the period of uncontrolled self-heating. Then compost is packed in boxes and pasteurized for 8 h at 56–60°C and continues at 45°C for up to 7 days to remove volatile NH_3 and to produce pathogen free substrate. After inoculation, compost is covered with a mixture of soil, peat, and chalk. The optimal temperature for mycelium growth is 24◦C, and the optimal temperature for fruiting body production is from 14 to 18◦C. The yield of mushrooms consists of around 1 kg from 1 kg of compost dry matter. Composition of compost could be changed depending on local availability of casing materials (Baysal et al., 2007).

Volvariella volvacea (paddy straw mushroom) also known as Chinese mushroom is also one of the most cultivated mushrooms of the world. It is grown mainly on rice straw, although other agricultural waste could be used. Generally, it prefers substrates with high content of cellulose and low content of lignin. Among the plant materials used for *V. volvacea* cultivation there are water hyacinth, oil palm bunch and pericarp waste, banana leaves, saw dust, cotton waste, and sugarcane bagasse (Ahlawat & Bindvi, 2016). Paddy straw is tied into bundles and immersed in water for 24 – 48 h. After removing excess water the straw is piled into heaps which are inoculated with *V. volvacea* pure cultures or spent compost from previous mushroom cultivation. The first crop of egg-like sporophores could be harvested in less than 1 month. The main disadvantage of *V. volvacea* production is very short shelf life even in cold storage because of autolysis. These mushrooms could be stored just for 3 days at 10 – 15°C. Therefore, straw mushrooms are best used in canned, pickled or dried form.

Ganoderma lucidum, a wood-destroying mushroom, having different pharmaceutical properties, is grown primarily for medicinal use, not as food. The common method for its cultivation is provided on wood logs or sawdust or wheat straw added with wheat bran, tea leaves and cotton husk in plastic bags or bottles. For cultivation on sawdust, addition of sucrose, 1%, and calcium carbonate, 1%, is recommended. For cultivation on wood, short pieces of wooden logs (15 cm or less in diameter and 15-24 cm in length) with moisture content of 35-40% are inoculated with mushroom mycelium, covered with soil, and then with chopped straw to ensure needed moisture and temperature. Short-log cultivation takes 4–5 months for mycelial incubation and fruiting bodies are harvested approximately after 25 days from primordia formation (Boh et al., 2007). Modern biotechnology gives the opportunity to produce mycelium biomass by their submerged cultivation in bioreactors. Cultivation of *G. lucidum* in synthetic liquid media is proposed for production of different valuable substances for medical use (Abdullah et al., 2020; Supramani et al., 2023; Zhao et al., 2011).

Flammulina velutipes, commonly known as golden needle mushroom or winter mushroom, is wood decaying mushroom growing in nature on the stumps of the Chinese hackberry tree, called enoki in Japanese, but also on some other trees such as aspens, willows, elms, mulberry and persimmon. Wild species have a brown color and short stem, while artificially grown ones are white with long thin stems. *F. velutipes* is the fifth largest edible mushroom in global production, which is especially popular in Asian countries, China, Japan, Republic of Korea, and Taiwan. *F. velutipes* could be cultivated on wood logs or on sawdust added with rice or wheat bran in polypropylene bags or plastic bottles (Harith et al., 2014; Sengar et al., 2019).

Solid-state and submerged liquid cultivation of mushrooms. Nowadays, for mushroom cultivation in industrial scale solid-state and submerged liquid fermentations could be used. Solid-state fermentation (SSF) involves the growth of mushrooms on a solid substrate, mainly an agro-industrial waste, meanwhile submerged cultivation is the growth of mushrooms in a liquid medium with dissolved nutrients under agitation and air supply. Application of solid substrate with low moisture content is advisable to produce mushroom fruit bodies for food or medicine, meanwhile cultivation of mushrooms in liquid media in bioreactors is a promising way to obtain mycelial biomass as an animal feed or for the production of metabolites (Letti et al., 2018).

SSF has such advantages as possibility of using a wide range of agro-industrial wastes as substrates for mushroom cultivation, relatively low energy consumption because of a lack of mechanical agitation/mixing and aeration, use of a residual substrate for bioremediation, animal feed, biofuel production, and biosynthesis of mushroom metabolites. However, when fermentation is carried out on a large scale, it is not so difficult but expensive to control the parameters of the cultivation process, such as pH, moisture content, homogeneity of substrate, concentration of oxygen, heat and mass transfer, and in addition, there is the possibility of contamination. On the other hand, SSF could be successfully used for production of certain biological active substances, for example, lignocellulolytic enzymes (Wang et al., 2019). Thus, the efficiency of SSF for the production of enzymes such as laccases, among others, is evident due to their wide industrial and technological applications; these SSF enzymatic potentialities may catalyze the oxidation of various phenolic compounds and a number of aromatic amines during the production of edible mushrooms of the genera *Pleurotus* (Han et al., 2020) or *Ganoderma* (Postemsky et al., 2017; Sharma et al., 2019).

Meanwhile, submerged cultivation is a very effective way to produce mushrooms in the form of mycelium biomass, especially for manufacturing of different valuable substances with health benefits. Liquid cultivation of mushrooms gives opportunity to control the fermentation process and final product quality and avoid contamination. The process takes place under a sterile environment in liquid medium at conditions optimal for the growth of selected mushrooms such as temperature, pH, mixing, and level of aeration (Bakratsas et al., 2021). Among the advantages of using submerged fermentation is the possibility of obtaining mushroom biomass or high-value bioactive substances in a short cultivation time for large-scale industrial applications. There are research studies devoted to production of truffles biomass using submerged fermentation, which is a promising way for business of this fungus (Tang et al., 2015). Application of liquid fermentation was proposed to produce bioactive metabolites such as triterpenoids, polysaccharides, antrodin, from medicinal mushroom *Antrodia cinnamomea* (Zhang et al., 2019). Cultivation of *Auricularia auricular* by this type of was proposed for melanin production (Sun et al., 2016). To synthesize exopolysaccharides by mycelial culture of *Inonotus obliquus* has also been done in liquid agitated conditions (Xiang et al., 2012).

Submerged mushroom cultivation is possible to use for production of mycoproteins, which possess high nutritional value and can be used in manufacturing of functional foods, for example in meat analogues production. Thus, cultivation of edible mushroom *Pleurotus ostreatus* LGAM was conducted in a stirred-tank bioreactor using aspen wood chips hydrolysate. The specific growth rate of mushroom was 1.8 ± 0.4 d^{-1}, biomass concentration was 25.0 ± 3.4 g/l, and protein yield consisted of 54.5 g per 100 g of sugars (Bakratsas et al., 2023).

Unusual method for mushroom cultivation. An interesting and unusual method is used to grow edible mushrooms of *Ustilago maydis* (huitlacoche or cuitlacoche) in Mexico and in some areas of Central America, where it has been traditionally produced, and of the USA, where huitlacoche has been recently used, as human food. There are clear evidences in different regions of Mexico that this fungus was in the common diet of the pre-Hispanic population. The maize, *Zea mays,* smut termed huitlacoche is characterized by the formation of galls or tumors in maize ears (Figure 7).

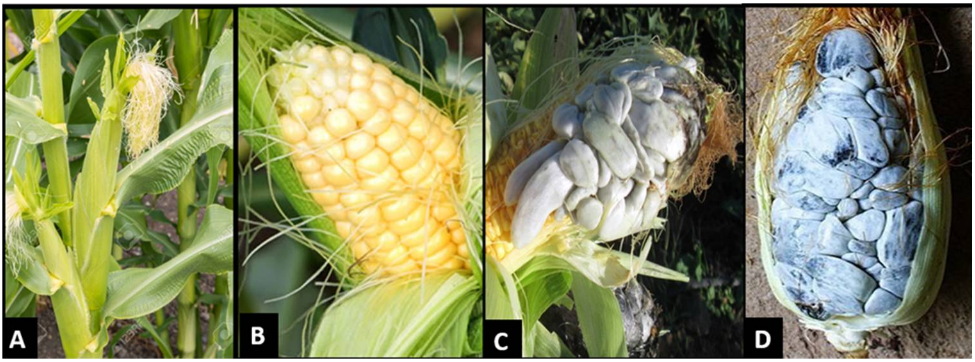

Figure 7. Ustilago maydis is responsible for corn smut:
A, maize plant; B, maize cob; c, maize infected by U. maydis; D, formation of galls of tumors

Ear galls are considered an edible delicacy produced by the natural infection of the maize ears with the fungus *Ustilago maydis*. These smut galls are also called as maize mushrooms, Mexican truffles, or maizteca mushrooms and serve as an important food source in this country. Nowadays huitlacoche is a culinary delight for international chefs in selected places in the USA, France, Spain, Japan and others. In addition to its unique flavor, huitlacoche has been identified as a high- quality functional food and could be included into the daily diet for its attractive characteristics, selected nutrients, valuable compounds, and nutraceutical potential.

Valdez-Morales et al (2010) found that chemical composition of huitlacoche may change due to maize genotype, stage of development, plant environment, and cooking process. This composition includes, in g/100 g DM: protein, 11.5-16.4; fat, 1.6-2.3; ash, 5.2-7.0; fiber, 16.0-23.5, and carbohydrates, 55.1-66.5 (Valverde et al., 1995). Amino acid lysine is present in huitlacoche in high amounts, 6.3 to 7.3 g/100 g protein; thus, it is an important source of this essential aminoacid, especially for consumers where cereal is the main component of the daily diet. Huitlacoche contains also high levels of polyunsaturated fatty acids with balanced ω-6/ω-3 ratio. The main fatty acid is the polyunsaturated omega-6 linoleic acid (18:2ω-6), 38.7-48.4 % from total amount of fatty acids, followed by another polyunsaturated omega-3 linolenic acid (18:3ω-3), 25.2-34.1%; saturated palmitic acid (16:0), 13.0-14.6%, and other residual fatty acids, 11.8-14.4% (Valverde and Paredes-López, 1993; Valverde et al., 1995). Optimal ω-6/ω-3 ratio in foods should be less than 4:1 (Stabnikova and Paredes-López, 2023); interestingly this ratio in huitlacoche varies from 1.1 to 1.9. Content of monosaccharides in huitlacoche, in mg/g of dry weight, is as follows: glucose, 140-180; fructose, 60-100; mannitol, 3.2; sorbitol, 4.5 (Juárez-Montiel et al., 2011; Valdez-Morales et al., 2010). Huitlacoche contains high amounts of phosphorus, 342.07 mg/kg, and magnesium, 262.69 mg/kg, as well as total phenolic compounds, 113.11 mg

GAE/kg, and flavonoids, 28.51 mg CE/kg (Aydoğdu & Gölükçü, 2017). It was reported that huitlacoche possesses important functional properties, namely, antioxidant, hypocholesterolemia, immunomodulatory, anticancer, anti-inflammatory, antidiabetic and antihypertensive (Juárez-Montiel et al., 2011; López-Martínez et al., 2022). Huitlacoche is sold in Mexico in domestic markets all over the country; and the commercial importance of this product is now increasing in high-income places of the U.S. and in some few other countries.

Conclusions

The role that the mushroom kingdom plays in human life is remarkable, and at the same time very important to be assessed. Simultaneously with the development of humanity, the function of mushrooms in human life has intensified and expanded. It started in the initial historical times, before the beginning of agriculture, as an additional source of nutrition, to become in the last decades as the object of large-scale industrial production using modern biotechnological procedures. The participation of mushrooms in human consumption and treatment has evolved from their use by healers and shamans to serious and careful clinical trials.

Wild edible mushrooms have a high nutritional value containing high-quality proteins, fibers, essential fatty acids, vitamins including D2, trace minerals, and such valuable compounds as polyphenols, terpenoids, sterols, while having low energetic value that allows them to be used in low-calorie diets.

Wild edible mushrooms contain many bioactive nutraceutical compounds and possess different specific pharmaceutical properties, which can be used in treatment of various serious diseases. However, more clinical trials on humans showing positive effect of orally administered mushroom consumption on health state are needed as well as regulations for food supplements with mushrooms, standards and protocols for the production and testing of mushroom products in general.

The gathering and use of wild edible mushrooms for food make a significant contribution to both the solution of the global food shortage crisis and economics of different countries around the world, and could be considered in some countries as new sources of income for local people.

The increase of interest on fungus consumption along human history at worldwide level has led to the development of basic and sophisticated techniques for their cultivation. Solid-state and submerged liquid fermentations are nowadays useful methods for cultivation of mushroom in a large-scale for their production including volumes of biomass and of very valuable specific bioactive metabolites. In brief, nowadays wild and cultivated procedures for the small and large scale production of mushrooms, and of fungal metabolites are playing, and much more will do it in the near future, outstanding roles in the use of raw materials and in the economy of populations of local people around the world; food, and pharmaceutical products and including industrial uses are their fields of utmost influence.

Acknowledges. The authors thank Dr. Talía Hernández-Pérez for the photos "Ustilago maydis is responsible for corn smut".

References

Abdullah N.R., Sharif F., Azizan N.H., Hafidz I.F.M., Supramani S., Usuldin S.R.A., Ahmad R., Wan-Mohtar W.A.A.Q.I. (2020), Pellet diameter of *Ganoderma lucidum* in a repeated-batch fermentation for the trio total production of biomass-exopolysaccharide-endopolysaccharide and its anti-oral cancer beta-glucan response, *AIMS Microbiology,* 6, pp. 379–400, https://doi.org/10.3934/microbiol.2020023

Ahlawat O.P., Bindvi A. (2016), Paddy straw mushroom (*Volvariella volvacea*) cultivation. In: S. Sharma, M. Singh, S. Prasad, H. Rathore (Eds.), *Mushrooms in India – diversity, improvement, cultivation, medicinal uses and value addition for rural development*, CRDT, IIT New Delhi, pp. 165-182.

Ahmad M.F. (2018), *Ganoderma lucidum*: Persuasive biologically active constituents and their health endorsement, *Biomedicine and Pharmacotherapy*, 107, pp. 507-519, https://doi.org/10.1016/j.biopha.2018.08.036

Ahn W.S., Kim D.J., Chae G.T., Lee J.M., Bae S.M., Sin J.I., Kim Y.W., Namkoong S.E., Lee I.P. (2004), Natural killer cell activity and quality of life were improved by consumption of a mushroom extract, *Agaricus blazei* Murill Kyowa, in gynecological cancer patients undergoing chemotherapy, *International Journal of Gynecological Cancer,* 14(4), pp. 589-594, https://doi.org/10.1111/j.1048-891X.2004.14403.x

AHP. (2006), Reishi mushroom *Ganoderma lucidum*. Standards of analysis, quality control, and therapeutics. In: American Herbal Pharmacopoeia and Therapeutic Compendium, Roy Upton Herbalist (ed.), Scotts Valley, USA 2006. http://www.medicinacomplementar.com.br/biblioteca/pdfs/Fitoterapia/fi-0405.pdf

Akcay C., Ceylan F., Arslan R. (2023), Production of oyster mushroom (*Pleurotus ostreatus*) from some waste lignocellulosic materials and FTIR characterization of structural changes, *Scientific Reports,* 13, 12897, https://doi.org/10.1038/s41598-023-40200-x

Alaimo M.G., Saitta A., Ambrosio E. (2019), Bedrock and soil geochemistry influence the content of chemical elements in wild edible mushrooms (*Morchella* group) from South Italy (Sicily), *Acta Mycologica*, 54(1), 1122, https://doi.org/10.5586/AM.1122

Alananbeh K.M., Bouqellah N.A., Al Kaff N.S. (2014), Cultivation of oyster mushroom *Pleurotus ostreatus* on date-palm leaves mixed with other agro-wastes in Saudi Arabia, *Saudi Journal of Biological Sciences,* 21(6), pp. 616-625, https://doi.org/10.1016/j.sjbs.2014.08.001

Amagase H., Nance D.M. (2008), A randomized, double-blind, placebo-controlled, clinical study of the general effects of a standardized *Lycium barbarum* (Goji) juice, GoChi, *Journal of Alternative and Complementary Medicine,* 14(4), pp. 403-412, https://doi.org/10.1089/acm.2008.0004

Andrejč D.C., Knez Ž., Knez M.M. (2022), Antioxidant, antibacterial, antitumor, antifungal, antiviral, anti-inflammatory, and nevro-protective activity of *Ganoderma lucidum*: An overview, *Frontiers in Pharmacology,* 13, 934982, https://doi.org/10.3389/fphar.2022.934982

Antonini E., Torri L., Piochi M., Cabrino G., Assunta M. (2020), Nutritional, antioxidant and sensory properties of functional beef burgers formulated with chia seeds and goji puree, before and after in vitro digestion, *Meat Science,* 161, 108021, https://doi.org/10.1016/j.meatsci.2019.108021

Anusiya G., Gowthama Prabu U., Yamini N.V., Sivarajasekar N., Rambabu K., Bharath G., Banat F. (2021), A review of the therapeutic and biological effects of edible and wild mushrooms, *Bioengineered,* 12(2), pp. 11239-11268, https://doi.org/10.1080/21655979.2021.2001183

Anzano A., Ammar M., Papaianni M., Grauso L., Sabbah M., Capparelli R., Lanzotti V. (2021), *Moringa oleifera* Lam.: A phytochemical and pharmacological overview. *Horticulturae,* 7(10), 409, https://doi.org/10.3390/horticulturae7100409

Aydoğdu M., Gölükçü M. (2017), Nutritional value of huitlacoche, maize mushroom caused by *Ustilago maydis*, *Food Science and Technology,* 37(4), pp. 531–535, https://doi.org/10.1590/1678-457x.19416

Ba D.M., Gao X., Al-Shaar L., Muscat J., Chinchilli V.M., Ssentongo P., Beelman R.B., Richie J. (2022), Mushroom intake and cognitive performance among US older adults: the National Health and Nutrition Examination Survey, 2011-2014. *British Journal of Nutrition,* 128(11), pp. 2241-2248, https://doi.org/10.1017/S0007114521005195

Badgujar S.B., Patel V.V., Bandivdekar A.H. (2014), *Foeniculum vulgare* Mill: a review of its botany, phytochemistry, pharmacology, contemporary application, and toxicology, *BioMed Research International*, 842674, https://doi.org/10.1155/2014/842674

Bajramova A., Spégel P.A (2022), Comparative study of the fatty acid profile of common fruits and fruits claimed to confer health benefits, *Journal of Food Composition and Analysis,* 112, 104657, http://dx.doi.org/10.1016/j.jfca.2022.104657

Bakratsas G., Polydera A., Katapodis P., Stamatis H. (2021), Recent trends in submerged cultivation of mushrooms and their application as a source of nutraceuticals and food additives, *Future Foods,* 4, 100086, https://doi.org/10.1016/j.fufo.2021.100086

Bakratsas G., Polydera A., Nilson O., Chatzikonstantinou A.V., Xiros C., Katapodis P., Stamatis H. (2023), Mycoprotein production by submerged fermentation of the edible mushroom *Pleurotus ostreatus* in a batch stirred tank bioreactor using agro-industrial hydrolysate, *Foods,* 12(12), 2295, https://doi.org/10.3390/foods12122295

Baliga M.S., Bhat H.P., Joseph N., Fazal F. (2011), Phytochemistry and medicinal uses of the bael fruit (*Aegle marmelos* Correa): A concise review, *Food Research International,* 44(7), pp. 1768-1775, https://doi.org/10.1016/J.FOODRES.2011.02.008

Barceló-Coblijn G., Murphy E.J. (2009), Alpha-linolenic acid and its conversion to longer chain n− 3 fatty acids: Benefits for human health and a role in maintaining tissue n− 3 fatty acid levels, *Progress in Lipid Research,* 48(6), pp. 355-374, http://dx.doi.org/10.1016/j.plipres.2009.07.002

Barros L., Baptista P., Correia D.M., Casal S., Oliveira B., Ferreira I.C.F.R. (2007), Fatty acid and sugar compositions and nutritional value of five wild edible mushrooms from Northeast Portugal, *Food Chemistry,* 105(1), pp. 140–145, https://doi.org/10.1016/j.foodchem.2007.03.052

Barros L., Cruz T., Baptista P., Estevinho L.M., Ferreira I.C.F.R, (2008a), Wild and commercial mushrooms as source of nutrients and nutraceuticals, *Food and Chemical Toxicology,* 46(8), pp. 2742–2747, https://doi.org/10.1016/j.fct.2008.04.030

Barros L., Venturini B.A., Baptista P., Estevinho L.M., Ferreira I.C.F.R. (2008b), Chemical composition and biological properties of Portuguese wild mushrooms: A comprehensive study, *Journal of Agricultural and Food Chemistry,* 56(10), pp. 3856–3862, https://doi.org/10.1021/jf8003114

Barros L., Falcão S., Baptista P., Freire C., Vilas-Boas M., Ferreira I.C.F.R. (2008c), Antioxidant activity of *Agaricus* sp. mushrooms by chemical, biochemical and electrochemical assays, *Food Chemistry,* 111(1), pp. 61–66, https://doi.org/10.1016/j.foodchem.2008.03.03

Barros L., Dueñas M., Ferreira I.C.F.R., Baptista P., Santos-Buelga C. (2009), Phenolic acids determination by HPLC–DAD–ESI/MS in sixteen different Portuguese wild mushrooms species, *Food and Chemical Toxicology,* 47(6), pp. 1076–1079, https://doi.org/10.1016/j.fct.2009.01.039

Baysal E., Yigitbasi O.N., Çolak M., Toker H., Şimşek H., Yilmaz F. (2007), Cultivation of *Agaricus bisporus* on some compost formulas and locally available casing materials. Part I: Wheat straw based compost formulas and locally available casing materials, *African Journal of Biotechnology,* 6(19), pp. 2225-2230, https://doi.org/10.5897/AJB2007.000-2349

Bello-Corral L., Sánchez-Valdeón L., Casado-Verdejo I., Seco-Calvo J.Á., Fernández-Fernández A.J., Fernández-Martínez N.M. (2021), The influence of nutrition in Alzheimer's disease: Neuroinflammation and the microbiome vs. transmissible prion, *Frontiers in Neuroscience,* 15, 677777, https://doi.org/10.3389/fnins.2021.677777

Beluhan S., Ranogajec A. (2011), Chemical composition and non-volatile components of Croatian wild edible mushrooms, *Food Chemistry,* 124(3), pp. 1076–1082, https://doi.org/10.1016/j.foodchem.2010.07.08

Bere E. (2007), Wild berries: a good source of omega-3, *European Journal of Clinical Nutrition,* 61(3), pp. 431-433, http://dx.doi.org/10.1038/sj.ejcn.1602512

Berger A., Rein D., Kratky E., Monnard I., Hajjaj H., Meirim I., Piguet-Welsch C., Hauser J., Mace K., Niederberger P. (2004), Cholesterol-lowering properties of *Ganoderma lucidum* in vitro, ex vivo, and in hamsters and minipigs, *Lipids in Health and Disease,* 3(1), 2, https://doi.org/10.1186/1476-511x-3-2

Bernas E. (2017), Monosodium glutamate equivalents and B-group vitamins in frozen mushrooms, *International Journal of Food Properties,* 20(S2), pp. 1613-1626, https://doi.org/10.1080/10942912.2017.1350973

Bertelsen C.D. (2013), *Mushroom: A Global History* (Edible), Reaktion Books.

Bharucha Z., Pretty J. (2010), The roles and values of wild foods in agricultural systems, *Philosophical Transactions of the Royal Society B: Biological Science,* 365(1554), pp. 2913-2926, https://doi.org/10.1098/rstb.2010.0123

Boh B., Berovic M., Zhang J., Zhi-Bin L. (2007), *Ganoderma lucidum* and its pharmaceutically active compounds, *Biotechnology Annual Review,* 13, 265-301, https://doi.org/10.1016/S1387-2656(07)13010-6

Bora P., Ragaeea S., Abdel-Aal E.S.M. (2019), Effect of incorporation of goji berry by-product on biochemical, physical and sensory properties of selected bakery products, *LWT – Food Science and Technology,* 112, 108225, https://doi.org/10.1016/j.lwt.2019.05.123

Borthakur M., Joshi S.R. (2019), Wild mushrooms as functional foods: the significance of inherent perilous metabolites, *New and Future Developments in Microbial Biotechnology and Bioengineering*, 1–12, https://doi.org/10.1016/b978-0-444-63504-4.00001-3

Budge E.A.W. (2017), *The Egyptian book of the dead: The papyrus of Ani in the British museum*, Wisehouse Classics.

Bulam S., Üstün N., Pekşen A. (2021), Effects of different processing methods on nutrients, bioactive compounds, and biological activities of Chanterelle mushroom (*Cantharellus cibarius*): A review, *European Food Science and Engineering,* 2(2), pp. 52-58, https://dergipark.org.tr/tr/download/article-file/2008937

Cağlarirmak N. (2011), Edible mushrooms: An alternative food item. In *Proceedings of the 7th International Conference on Mushroom Biology and Mushroom Products*

(ICMBMP7), World Society for Mushroom Biology and Mushroom Products, Arcachon, France, 4–7 October 2011; pp. 548–554.

Cardwell G., Bornman J.F., James A.P., Black L.J. (2018), A review of mushrooms as a potential source of dietary vitamin D, *Nutrients,* 10(10), 1498, https://doi.org/10.3390/nu10101498

Carod-Artal F.J. (2015), Hallucinogenic drugs in pre-Columbian Mesoamerican cultures, *Neurologia,* 30(1), pp. 42-49, https://doi.org/10.1016/j.nrl.2011.07.003

Charoenngam N., Shirvani A., Holick M.F. (2019), Vitamin D for skeletal and non-skeletal health: What we should know, *Journal of Clinical Orthopaedics and Trauma,* 10(6), pp. 1082-1093, https://doi.org/10.1016/j.jcot.2019.07.004

Chan S.W., Tomlinson B., Chan P., Lam C.W.K. (2021), The beneficial effects of *Ganoderma lucidum* on cardiovascular and metabolic disease risk, *Pharmaceutical Biology,* 59(1), pp. 1161-1171, https://doi.org/10.1080/13880209.2021.1969413

Chang S.T. (2006), The world mushroom industry, *Trends and Technological Development*, 8(4), pp. 297-314, https://doi.org/10.1615/IntJMedMushr.v8.i4.10

Cheah I., Feng L., Tang R.M.Y., Lim K.H.M., Halliwell B. (2016), Ergothioneine levels in an elderly population decrease with age and incidence of cognitive decline; a risk factor for neurodegeneration? *Biochemical and Biophysical Research Communications,* 478(1), pp. 162-167, https://doi.org/10.1016/j.bbrc.2016.07.074

Chu T.T.W., Benzie I.F.F., Lam C.W.K., Fok B.S.P., Lee K.K.C., Tomlinson, B. (2012), Study of potential cardioprotective effects of *Ganoderma lucidum* (Lingzhi): Results of a controlled human intervention trial, *British Journal of Nutrition,* 107(7), pp. 1017–1027, https://doi.org/10.1017/S0007114511003795

Corona P., Cutini A., Chiavetta U., Paoletti E. (2016), Forest-food nexus: a topical opportunity for human well-being and silviculture, *Annals of Silvicultural Research,* 40(1), pp. 1-10, https://doi.org/10.12899/asr-1181

Graeme K.A. (2014), Mycetism: A review of the recent literature, *Journal of Medical Toxicology,* 10(2), pp. 173–189, https://doi.org/10.1007/s13181-013-0355-2

Das N., Mukherjee M. (2007), Cultivation of *Pleurotus ostreatus* on weed plants, *Bioresource Technology,* 98(14), pp. 2723-2726, https://doi.org/10.1016/j.biortech.2006.09.061

De Frutos Madrazo P., Martínez-Peña F., Esteban S. (2012), Edible wild mushroom tourism as a source of income and employment in rural areas. The case of Castilla y León. *Forest Systems,* 21(1), pp. 81-98, https://doi.org/10.5424/fs/2112211-02545

Dejene T., Oria-de-Rueda J.A., Martín-Pinto P. (2017), Wild mushrooms in Ethiopia: A review and synthesis for future perspective. *Forest Systems,* 26, 02, https://doi.org/10.5424/FS/2017261-10790

Deng G., Lin H., Seidman A., Fornier M., D'Andrea G., Wesa K., Yeung S., Cunningham-Rundles S., Vickers A.J., Cassileth B. (2008), A phase I/II trial of a polysaccharide extrct from *Grifola Frondosa* (Maitake mushroom) in breast cancer patients: Immunological effects, *Journal of Clinical Oncology,* 26(15), pp. 1215–1221, https://doi.org/10.1007/s00432-009-0562-z

Di Y.M., Sun L., Lu C., Guo X.F., Tang X., Zhang A.L., Fan G., Xue C.C. (2022), Benefits of herbal formulae containing *Poria cocos* (Fuling) for type 2 diabetes mellitus: A systematic review and meta-analysis, *PLoS One,* 17(12), e0278536, https://doi.org/10.1371/journal.pone.0278536

Dimopoulou M., Kolonas A., Mourtakos S., Androutsos O., Gortzi O. (2022), Nutritional composition and biological properties of sixteen edible mushroom species, *Applied Sciences,* 12(16), 8074, https://doi.org/10.3390/app12168074

Dubost N.J., Ou B., Beelman R.B. (2007), Quantification of polyphenols and ergothioneine in cultivated mushrooms and correlation to total antioxidant capacity, *Food Chemistry,* 105, pp. 727-35, https://doi.org/10.1016/j.foodchem.2007.01.0

Duru K.C., Kovaleva E.G., Danilova I.G., van der Bijl P. (2019), The pharmacological potential and possible molecular mechanisms of action of *Inonotus obliquus* from preclinical studies, *Phytotherapy Research,* 33(8), pp. 1966-1980, https://doi.org/10.1002/ptr.638

El Enshasy H.A., Hatti-Kaul R. (2013), Mushroom immunomodulators: unique molecules with unlimited applications, *Trends in Biotechnology,* 31(12), pp. 668-677, https://doi.org/10.1016/j.tibtech.2013.09.003

El Sheikha A.F. (2022), Nutritional profile and health benefits of *Ganoderma lucidum* “Lingzhi, Reishi, or Mannentake” as functional foods: Current scenario and future perspectives, *Foods,* 11(7), 1030, https://doi.org/10.3390/foods11071030

Feng L., Cheah I.K., Ng M.M., Li J., Chan S.M., Lim S.L., Mahendran R., Kua E.H., Halliwell B. (2019), The association between mushroom consumption and mild cognitive impairment: A community-based cross-sectional study in Singapore, *Journal of Alzheimer's Disease,* 68(1), pp. 197-203, https://doi.org/10.3233/JAD-180959

Ferreira I.C.F.R., Heleno S.A., Reis F.S., Stojkovic D., Queiroz M.J., Vasconcelos M.H., Sokovic M. (2015), Chemical features of *Ganoderma polysaccharides* with antioxidant, antitumor and antimicrobial activities, *Phytochemistry,* 114, pp. 38-55, https://doi.org/10.1016/j.phytochem.2014.10.011

Fortes R.C., Recôva V.L., Melo A.L., Novaes M.R. (2008), Effects of dietary supplementation with medicinal fungus in fasting glycemia levels of patients with colorectal cancer: a randomized, double-blind, placebo-controlled clinical study, *Nutricion Hospitalaria,* 23(6), pp. 591-598, Available online: https://scielo.isciii.es/pdf/nh/v23n6/original8.pdf

Fortes R.C., Novaes M.R.C.G., Recova V.L., Melo A.L. (2009), Immunological, hematological, and glycemia effects of dietary supplementation with *Agaricus sylvaticus* on patients' colorectal cancer, *Experimental Biology and Medicine,* 234(1), pp. 53-62, https://doi.org/10.3181/0806-rm-193

Frost M. (2016), *Three popular medicinal mushroom supplements: A review of human clinical trials,* Brigham Young University, Faculty Publications, 1609, Available online: https://scholarsarchive.byu.edu/cgi/viewcontent.cgi?article=2619&context=facpub

Gargano M.L., van Griensven L.J.L.D., Isikhuemhen O.S., Lindequist U., Venturella G., Wasser, S.P., Zervakis G.I. (2017), Medicinal mushrooms: Valuable biological resources of high exploitation potential, *Plant Biosystems – An International Journal Dealing with all Aspects of Plant Biology,* 151(3), pp. 548-565, https://doi.org/10.1080/11263504.2017.1301590

Gao Y.H., Zhou S.F., Jiang W.Q., Huang M., Sai X.H. (2003a), Effects of Ganopoly (a *Ganoderma lucidum* polysaccharide extract) on immune functions in advanced-stage cancer patients. *Immunological Investigations,* 32, pp. 201–215, https://doi.org/10.1081/imm-120022979

Gao Y.H., Sai X.H., Chen G.L., Ye J.X., Zhou S.F. (2003b), A randomized, placebo-controlled, multi-center study of *Ganoderma lucidum* (W. Curt.: Fr.) Lloyd (*Aphyllophoromycetideae*) polysaccharides (Ganopoly®) in patients with advanced lung cancer, *International Journal of Medicinal Mushrooms,* 5, pp. 368–381, https://doi.org/10.1615/InterJMedicMush.v5.i4.40

Gao Y., Lan J., Dai X., Ye J., Zhou S. (2004a), A phase I/II study of Lingzhi mushroom *Ganoderma lucidum* (W. Curt.: Fr.) Lloyd (*Aphyllophoromycetideae*) extract in patients with type II diabetes mellitus, *International Journal of Medicinal Mushrooms,* 6*(*1), pp. 33–40, https://doi.org/10.1615/IntJMedMushr.v6.i1.30

Gao Y., Chen G., Dai X., Ye J., Zhou S. (2004b), A phase I/II study of ling zhi mushroom *Ganoderma lucidum* (W. Curt.: Fr.) Lloyd (*Aphyllophoromycetideae*) extract in patients with coronary heart disease, *International Journal of Medicinal Mushrooms,* 6(4), pp. 327-334, https://doi.org/10.1615/IntJMedMushr.v6.i4.30

Gariboldi M.B., Marras E., Ferrario N., Vivona V., Prini P., Vignati F., Perletti G. (2023), Anti-cancer potential of edible/medicinal mushrooms in breast cancer, *International Journal of Molecular Sciences,* 24(12), 10120, https://doi.org/10.3390/ijms241210120

Guinard J.X., Myrdal Miller A., Mills K., Wong T., Lee S.M., Sirimuangmoon C., Schaefer S.E., Drescher G. (2016), Consumer acceptance of dishes in which beef has been partially substituted with mushrooms and sodium has been reduced, *Appetite,* 105, pp. 449-459, https://doi.org/10.1016/j.appet.2016.06.018

Han M.L., An Q., He S.F., Zhang X.L., Zhang M.H., Gao X.H., Wu Q., Bian L.S. (2020), Solid-state fermentation on poplar sawdust and corncob wastes for lignocellulolytic enzymes by different *Pleurotus ostreatus* strains, *BioResources,* 15(3), pp. 4982-4995, https://doi.org/10.15376/biores.15.3.4982-4995

Hanuš L.O., Shkrob I., Dembitsky V.M. (2008), Lipids and fatty acids of wild edible mushrooms of the genus *Boletus*, *Journal of Food Lipids,* 15(3), pp. 370–383, https://doi.org/10.1111/j.1745-4522.2008.00125.x

Hao Z., Zhang W., Tian F., Wei R., Pan X. (2022), Enhancing the nutritional and functional properties of *Auricularia auricula* through the exploitation of walnut branch waste, *Foods,* 11(20), 3242, https://doi.org/10.3390/foods11203242

Harith N., Abdullah N., Sabaratnam V. (2014), Cultivation of *Flammulina velutipes* mushroom using various agro-residues as a fruiting substrate, *Pesquisa Agropecuária Brasileira,* 49(3), pp. 181–188, https://doi.org/10.1590/S0100-204X2014000300004

Hernández D., Sánchez J.E., Yamasaki K.A (2003), Simple procedure for preparing substrate for *Pleurotus ostreatus* cultivation, *Bioresource Technology,* 90(2), pp. 45-150, https://doi.org/10.1016/s0960-8524(03)00118-4

Hsu C.H., Liao Y.L., Lin S.C., Hwang K.C., Chou P. (2007), The mushroom *Agaricus blazei* Murill in combination with metformin and gliclazide improves insulin resistance in type 2 diabetes: A randomized, double-blinded, and placebo-controlled clinical trial, *Journal of Alternative and Complementary Medicine,* 13(1), pp. 97-102, https://doi.org/10.1089/acm.2006.6054

Ito T., Kobayashi T., Egusa C., Maeda T., Abe N., Okubo Y., Tsuboi R., Niitsuma T. (2020), A case of food allergy due to three different mushroom species, *Allergology International,* 69(1), pp. 152-153, https://doi.org/10.1016/j.alit.2019.08.003

Ivanov V., Shevchenko O., Marynin A., Stabnikov V., Gubenia O., Stabnikova O., Shevchenko A., Gavva O., Saliuk A. (2021), Trends and expected benefits of the breaking edge food technologies in 2021–2030, *Ukrainian Food Journal,* 10(1), pp. 7-36, https://doi.org/10.24263/2304-974X-2021-10-1-3

Jatwa T.K., Apet K.T., Wagh S.S., Sayyed K.S., Rudrappa K.B., Sornapriya S.P. (2016), Evaluation of various agro-wastes for production of *Pleurotus* spp. (*P. florida*, *P. sajor-caju* and *P. eous*), *Journal of Pure and Applied Microbiology,* 10(4), pp. 2783–2792, http://dx.doi.org/10.22207/JPAM.10.4.37

Jaworska G., Pogon K., Skrzypczak A., Bernas E. (2015), Composition and antioxidant properties of wild mushrooms *Boletus edulis* and *Xerocomus badius* prepared for consumption, *Journal of Food Science and Technology,* 52(12), pp. 7944–7953, https://doi.org/ 10.1007/s13197-015-1933-x

Jayachandran M., Xiao J., Xu B. (2017), A critical review on health promoting benefits of edible mushrooms through gut microbiota, *International Journal of Molecular Science,* 8(9), 1934, https://doi.org/10.3390/ijms18091934

Juárez-Montiel M., Ruiloba de León S., Chávez-Camarillo G., Hernández-Rodríguez C., Villa-Tanaca L. (2011), Huitlacoche (corn smut), caused by the phytopathogenic fungus *Ustilago maydis*, as a functional food, *Revista Iberoamericana de Micología,* 28, pp. 69–73, https://doi:10.1016/j.riam.2011.01.001

Kalač P. (2009), Chemical composition and nutritional value of European species of wild growing mushrooms: A review, *Food Chemistry,* 113(1), pp. 9–16, https://doi.org/10.1016/j.foodchem.2008.07.077

Kalaras M.D., Richie J.P., Calcagnotto A., Beelman R.B. (2017), Mushrooms: A rich source of the antioxidants ergothioneine and glutathione, *Food Chemistry,* 233, pp. 429– 433, https://doi.org/10.1016/j.foodchem.2017.04.109

Keegan R.J., Lu Z., Bogusz J.M., Williams J.E., Holick M.F. (2013), Photobiology of vitamin D in mushrooms and its bioavailability in humans, *Dermatoendocrinology,* 5, pp. 165–176, https://doi.org/10.4161/derm.23321

Keleş A., Koca I., Gençcelep H. (2011), Antioxidant properties of wild edible mushrooms, *Journal of Food Processing & Technology,* 2, pp. 3-6, https://doi.org/10.4172/2157-7110.1000130

Kobayashi T., Ito T., Egusa C., Maeda T., Abe N., Okubo Y., Tsuboi R. (2019), A case of anaphylaxis due to alpha-mannosidase from *Auricularia*, *Allergology International,* 68(3), pp. 394-395, https://doi.org/10.1016/j.alit.2019.02.008

Kristensen H.L., Rosenqvist E., Jakobsen J. (2012), Increase of vitamin D2 by UV-B exposure during the growth phase of white button mushroom (*Agaricus bisporus*), *Food and Nutrition Research,* 56, 7114, https://doi.org/10.3402/fnr.v56i0.7114

Lallawmsanga, Passari A.K., Mishra V.K., Leo V.V., Singh B.P., Valliammai Meyyappan G.V., Gupta V.K., Uthandi S., Upadhyay R.C. (2016), Antimicrobial potential, identification and phylogenetic affiliation of wild mushrooms from two sub-tropical semi-evergreen Indian forest ecosystems, *PLoS One,* 11(11), e0166368, https://doi.org/10.1371/journal.pone.0166368

Lee S., Lee H.Y., Park Y., Ko E.J., Ban T.H., Chung B.H., Lee H.S., Yang C.W. (2020), Development of end stage renal disease after long-term ingestion of Chaga mushroom: Case report and review of literature, *Journal of Korean Medical Science,* 35(19), e122, https://doi.org/10.3346/jkms.2020.35.e122

Letti L.A., Vítola F.M., Pereira G.V., Karp S.G., Medeiros A.B., Costa E.S., Bissoqui L., Soccol C.R. (2018), Solid-state fermentation for the production of mushrooms. In: A. Pandey, C. Larroche, C.R. Soccol (Eds.), *Current Developments in Biotechnology and Bioengineering*, Elsevier, pp. 285-318, https://doi.org/10.1016/B978-0-444-63990-5.00014-1

Li X., Ma L., Zhang L. (2019), Molecular basis for *Poria cocos* mushroom polysaccharide used as an antitumor drug in China, *Progress in Molecular Biology and Translational Science,* 163, pp. 263-296, https://doi.org/10.1016/bs.pmbts.2019.02.011

Li I.C., Chang H.H., Lin C.H., Chen W.P., Lu T.H., Lee L.Y., Chen Y.W., Chen Y.P., Chen C.C., Lin D.P.C. (2020), Prevention of early Alzheimer's disease by erinacine a-enriched *Hericium erinaceus* mycelia pilot double-blind placebo-controlled study, *Frontiers in Aging Neuroscience,* 12, 155, https://doi.org/10.3389/fnagi.2020.00155

Li H., Tian Y., Menolli N.Jr., Ye L., Karunarathna S.C., Perez-Moreno J., Rahman M.M., Rashid M.H., Phengsintham P., Rizal L., Kasuya T., Lim Y.W., Dutta A.K., Khalid A.N., Huyen L.T., Balolong M.P., Baruah G., Madawala S., Thongklang N., Hyde K.D., Kirk P.M., Xu J., Sheng J., Boa E., Mortimer P.E. (2021), Reviewing the world's edible mushroom species: A new evidence-based classification system, *Comprehensive Reviews in Food Science and Food Safety,* 20(2), pp. 1982-2014, https://doi.org/10.1111/1541-4337.12708

Li G., Wang Y., Yu D., Zhu P., Zhao G., Liu C., Zhao H. (2022), Ligninolytic characteristics of *Pleurotus ostreatus* cultivated in cotton stalk media, *Frontiers in Microbiology,* 13, 1035040, https://doi.org/10.3389/fmicb.2022.1035040

Li N., Li H., Liu Z., Feng G., Shi C., Wu Y. (2023), Unveiling the therapeutic potentials of mushroom bioactive compounds in Alzheimer’s disease, *Foods,* 12(15), 2972, https://doi.org/10.3390/foods12152972

Lindequist U., Niedermeyer T.H.J., Jülich W.D. (2005), The pharmacological potential of mushrooms, *Evidence-based Complementary and Alternative Medicine,* 2, 906016, https://doi.org/10.1093/ecam/neh107

Llorent-Martínez E.J., Fernández-de Córdova M.L., Ortega-Barrales P., Ruiz-Medina A. (2013), Characterization and comparison of the chemical composition of exotic superfoods, *Microchemical Journal,* 110, pp. 444–451, https://doi.org/10.1016/j.microc.2013.05.016

López-Martínez L.X., Aguirre-Delgado A., Saenz-Hidalgo H.K., Buenrostro-Figueroa J.J., García H.S., Baeza-Jiménez R. (2022), Bioactive ingredients of huitlacoche (*Ustilago maydis*), a potential food raw material, *Food Chemistry*, 4, 100076, https://doi.org/10.1016/j.fochms.2022.100076

Lu Y., Jia Y., Xue Z., Li N., Liu J., Chen H. (2021), Recent developments in *Inonotus obliquus* (Chaga mushroom) polysaccharides: Isolation, structural characteristics, biological activities and application, *Polymers (Basel),* 13(9), 1441, https://doi.org/10.3390/polym13091441

Luczaj L., Stawarczyk K., Kosiek T., Pietras M., Kujawa A. (2015), Wild food plants and fungi used by Ukrainians in the western part of the Maramures region in Romania, *Acta Societatis Botanicorum Poloniae,* 84(3), pp. 339-346, https://doi.org/10.5586/asbp.2015.029

Machado-Carvalho L., Martins T., Aires A., Saavedra M.J., Marques G. (2023), Antioxidant, antibacterial, and cosmeceutical potential of four common edible mushrooms, *Applied Sciences,* 13(13), 7357, https://doi.org/10.3390/app13137357

Manzi P., Aguzzi A., Pizzoferrato L. (2001), Nutritional value of mushrooms widely consumed in Italy, *Food Chemistry,* 73(3), pp. 321-325, https://doi.org/10.1016/s0308-8146(00)00304-6

Martínez-Montemayor M.M., Ling T., Suárez-Arroyo I.J., Ortiz-Soto G., Santiago-Negrón C.L., Lacourt-Ventura M.Y., Valentín-Acevedo A., Lang W.H., Rivas F. (2019), Identification of biologically active *Ganoderma lucidum* compounds and synthesis of improved derivatives that confer anti-cancer activities in *vitro, Frontiers in Pharmacology,* 10,115, https://doi.org/10.3389/fphar.2019.00115

Mattila P.H., Piironen V.I., Uusi-Rauva E.J., Koivistoinen P.E. (1994), Vitamin D contents in edible mushrooms, *Journal of Agricultural and Food Chemistry,* 42(11), pp. 2449–2453, https://doi.org/10.1021/jf00047a016

Mehrotra A., Calvo M.S., Beelman R.B., Levy E., Siuty J., Kalaras M.D., Uribarri J. (2014), Bioavailability of vitamin D2 from enriched mushrooms in prediabetic adults: A randomized controlled trial, *European Journal of Clinical Nutrition,* 68, pp. 1154–1160, https://doi.org/10.1038/ejcn.2014.157

Milla P.G., Penalver R., Nieto G. (2021), Health benefits of uses and applications of *Moringa oleifera* in bakery products, *Plants,* 10(2), 318, https://doi.org/10.3390/plants10020318

Moore D., Robson G., Trinci A. (2020), *21st Century Guidebook to Fungi* (2nd ed.). Cambridge, Cambridge University Press, https://doi.org/10.1017/9781108776387

Mori K., Inatomi S., Ouchi K., Azumi Y., Tuchida T. (2009), Improving effects of the mushroom Yamabushitake (*Hericium erinaceus*) in mild cognitive impairment: A double-blind placebo-controlled trial, *Phytotherapy Research*, *23*(3), pp. 367–372, https://doi.org/10.1002/ptr.2634

Muszyńska B., Ziaja K., Ekiert H. (2013), Phenolic acids in selected edible basidiomycota species: *Armillaria mellea, Boletus badius, Boletus edulis, Cantharellus cibarius, Lactarius deliciosus* and *Pleurotus ostreatus*, *Acta Scientiarum Polonorum, Hortorum Cultus,* 12, pp. 107–116.

Muszyńska B., Kała K., Rojowski J., Grzywacz A., Opoka W. (2017), Composition and biological properties of *Agaricus bisporus* fruiting bodies—A review, *Polish Journal of Food and Nutrition Sciences,* 67, pp. 173–181, https://doi.org/10.1515/pjfns-2016-0032

Myrdal Miller A., Mills K., Wong T., Drescher G., Lee S.M., Sirimuangmoon C., Schaefer S., Langstaff S., Minor B., Guinard J.X. (2014), Flavor-enhancing properties of mushrooms in meat-based dishes in which sodium has been reduced and meat has been partially substituted with mushrooms, *Journal of Food Science,* 79(9), pp. 795-804, https://doi.org/10.1111/1750-3841.12549

Muszyńska B., Grzywacz-Kisielewska A., Kała K., Gdula-Argasińska J. (2018), Anti-inflammatory properties of edible mushrooms: A review, *Food Chemistry,* 243, pp. 373-381, https://doi.org/10.1016/j.foodchem.2017.09.149

Lincoff G.H. (1981). *National Audubon society field guide to mushrooms*, Knopf.

Niksic M., Klaus A., Argyropoulos D. (2016), Safety of foods based on mushrooms. In: V. Prakash, O. Martín-Belloso, L. Keener, S. Astley, S. Braun, H. McMahon, H. Lelieveld (Eds.), *Regulating Safety of Traditional and Ethnic Foods*, Elsevier, pp. 421–439, https://doi.org/10.1016/b978-0-12-800605-4.00022-0

Novakovic S., Djekic I., Klaus A., Vunduk J., Djordjevic V., Tomović V., Šojić B., Kocić-Tanackov S., Lorenzo J.M., Barba F.J., Tomasevic I. (2019), The Effect of *Cantharellus cibarius* addition on quality characteristics of frankfurter during refrigerated storage, *Foods,* 8(12), 635, https://doi.org/10.3390/foods8120635

Novakovic S., Dekic I., Klaus A., Vunduk J., Dorđevic V., Tomović V., Šojić B., Kocić-Tanackov S., Tomašević I. (2020), Antioxidant activity of mushrooms in vitro and in frankfurters, *Meat Technology,* 61, pp. 62-69, https://doi.org/10.18485/meattech.2020.61.1.5

Nowakowski P., Markiewicz-Zukowska R., Soroczynska J., Puścion-Jakubik A., Mielcarek K., Borawska M.H., Socha K. (2021), Evaluation ˙of toxic element content and health risk assessment of edible wild mushrooms, *Journal of Food Composition and Analysis,* 96, 103698, https://doi.org/10.1016/j.jfca.2020.103698

Oba K., Kobayashi M., Matsui T., Kodera Y., Sakamoto J. (2009), Individual patient based meta-analysis of lentinan for unresectable/recurrent gastric cancer, *Anticancer*

Research, 29(7), pp. 2739-2745, Available online 24.07.2023 https://ar.iiarjournals.org/content/anticanres/29/7/2739.full.pdf
Okuno K., Uno K. (2011), Efficacy of orally administered *Lentinula edodes* mycelia extract for advanced gastrointestinal cancer patients undergoing cancer chemotherapy: A pilot study, *Asian Pacific Journal of Cancer Prevention,* 12(7), pp. 1671-1674.
Outila T.A., Mattila P.H., Piironen V.I., Lamberg-Allardt C.J. (1999), Bioavailability of vitamin D from wild edible mushrooms (*Cantharellus tubaeformis*) as measured with a human bioassay, *American Journal of Clinical Nutrition,* 69(1), pp. 95-98, https://doi.org/10.1093/ajcn/69.1.95
Ouzouni P.K., Riganakos K.A. (2007), Nutritional value and metal content of Greek wild edible fungi, *Acta Alimentaria,* 36, pp. 99–110, https://doi.org/10.1016/j.foodchem.2009.02.014
Palacios I., Lozano M., Moro C., D'Arrigo M., Rostagno M.A., Martínez J.A., García-Lafuente A., Guillamón E., Villares A. (2011), Antioxidant properties of phenolic compounds occurring in edible mushrooms. *Food Chemistry,* 128(3), pp. 674–678, https://doi.org/10.1016/j.foodchem.2011.03.08
Paloi S., Kumla J., Paloi B.P., Srinuanpan S., Hoijang S., Karunarathna S.C., Acharya K., Suwannarach N., Lumyong S. (2023), Termite mushrooms (*Termitomyces*), a potential source of nutrients and bioactive compounds exhibiting human health benefits: A review, *Journal of Fungi,* 9(1), 112, https://doi.org/10.3390/jof9010112
Panda S.K., Sahoo G., Swain S.S., Luyten W. (2022), Anticancer activities of mushrooms: A neglected source for drug discovery, *Pharmaceuticals,* 15(2), 176, https://doi.org/10.3390/ph15020176
Patel S., Goyal A. (2012), Recent developments in mushrooms as anti-cancer therapeutics: A review, *3 Biotech,* 2(1), pp. 1-15, https://doi.org/10.1007/s13205-011-0036-2
Peintner U., Schwarz S., Mešić A., Moreau P.A., Moreno G., Saviuc P. (2013), Mycophilic or mycophobic? Legislation and guidelines on wild mushroom commerce reveal different consumption behaviour in European countries, *PLoS ONE*, 8, e63926e63926, https://doi.org/10.1371/journal.pone.0063926
Pérez-Moreno J., Mortimer P.E., Xu J., Karunarathna S.C., Li H. (2021), Global perspectives on the ecological, cultural and socioeconomic relevance of wild edible fungi, *Studies in Fungi,* 6(1), pp. 408–424, https://doi.org/10.5943/sif/6/1/31
Postemsky P.D., Bidegain M.A., Gonzalez-Matute R., Figlas N.D., Cubitto, M. A. (2017), Pilot-scale bioconversion of rice and sunflower agro-residues into medicinal mushrooms and laccase enzymes through solid-state fermentation with *Ganoderma lucidum*, *Bioresource Technology,* 231, pp. 85-93, https://doi.org/10.1016/j.biortech.2017.01.064
Procházka P., Soukupová J., Mullen K.J., Tomšík K.Jr., Čábelková I. (2023), Wild mushrooms as a source of protein: A case study from Central Europe, especially the Czech Republic, *Foods,* 12(5), 934, https://doi.org/10.3390/foods12050934
Rahi D.K., Malik D. (2016), Diversity of mushrooms and their metabolites of nutraceutical and therapeutic significance, *Journal of Mycology,* 76541231, https://doi.org/10.1155/2016/7654123
Raman J., Jang K.Y., Oh Y.L., Oh M., Im J.H., Lakshmanan H., Sabaratnam V. (2020), Cultivation and nutritional value of prominent *Pleurotus* spp.: An overview. *Mycobiology,* 49(1), pp. 1-14, https://doi.org/10.1080/12298093.2020.1835142
Rangel-Vargas E., Rodriguez J.A., Domínguez R., Lorenzo J.M., Sosa M.E., Andrés S.C., Rosmini M., Pérez-Alvarez J.A., Teixeira A., Santos E.M. (2021), Edible mushrooms

as a natural source of food ingredient/additive replacer, *Foods,* 10(11), 2687, https://doi.org/10.3390/foods10112687

Reis F.S., Stojković D., Barros L., Glamočlija J., Ćirić A., Soković M., Martins A., Vasconcelos M.H., Morales P., Ferreira I.C.F.R. (2014), Can *Suillus granulatus* (L.) Roussel be classified as a functional food? *Food and Function,* 5(11), pp. 2861-2869, https://doi.org/10.1039/c4fo00619d

Report. (2023), Chaga mushroom-based products: Global strategic business report. *Global Industry Analysts*, Inc. Available online on 23.07.2023: https://www.researchandmarkets.com/reports/5139721/chaga-mushroom-based-products-global-strategic

Ribeiro B., Guedes de Pinho P., Andrade P.B., Baptista P., Valentão P. (2009), Fatty acid composition of wild edible mushrooms species: A comparative study, *Microchemical Journal,* 93(1), pp. 29–35, https://doi.org/10.1016/j.microc.2009.04.005

Román M., Boa E. (2006), The marketing of *Lactarius deliciosus* in northern Spain, *Economic Botany,* 60, pp. 284–290, https://doi.org/10.1663/0013-0001(2006)60[284:TMOLDI]2.0.CO;2

Roncero-Ramos I., Delgado-Andrade C. (2017), The beneficial role of edible mushrooms in human health, *Current Opinion in Food Science,* 14, pp. 122–128,https://doi.org/10.1016/j.cofs.2017.04.002

Royse D.J., Baars J., Tan Q. (2017), Current overview of mushroom production in the world, In: D.C. Zied, A. Pardo-Giminez (Eds.), *Edible and Medicinal Mushrooms: Technology and Applications*, John Wiley & Sons Ltd., Hoboken, NJ, USA, pp. 5–13, https://doi.org/10.1002/9781119149446.ch2

Sadiq S., Mahmood-ul-Hassan M., Rafiq N., Ahad K. (2019), Spent mushroom compost of *Pleurotus ostreatus*: A tool to treat soil contaminated with endosulfan, *Compost Science & Utilization,* 27(4), pp. 193-204, https://doi.org/10.1080/1065657X.2019.1666067

Samorini G. (2001), New data from the ethnomycology of psychoactive mushrooms, *International Journal of Medicinal Mushrooms,* 3(2-3), pp. 96-118, https://doi.org/10.1615/IntJMedMushr.v3.i2-3.1670

Sande D., de Oliveira G.P., Moura M.A.F., de Almeida Martins B., Lima M. T.N.S., Takahashi J.A. (2019), Edible mushrooms as a ubiquitous source of essential fatty acids, *Food Research International,* 125, 108524, https://doi.org/10.1016/j.foodres.2019.108524

Savoie J.M., Largeteau M.L. (2011), Production of edible mushrooms in forests: Trends in development of a mycosilviculture, *Applied Microbiology and Biotechnology,* 89(4), pp. 971-979, https://doi.org/ 10.1007/s00253-010-3022-4

Sengar R.S., Singh A., Singh G. (2019), Cultivation of winter mushroom (*Flammulina velutipes*), *Indian Farmers' Digest,* 52(11), pp. 7-10.

Sharma A., Jain K.K., Srivastava A., Shrivastava B., Thakur V.V., Jain R.K., Kuhad R.C. (2019), Potential of in situ SSF laccase produced from *Ganoderma lucidum* RCK 2011 in biobleaching of paper pulp, *Bioprocess and Biosystems Engineering,* 42(3), pp. 367-377, https://doi.org/10.1007/s00449-018-2041-x

Sileshi G.W., Tibuhwa D.D., Mlambo A. (2023), Underutilized wild edible fungi and their undervalued ecosystem services in Africa, *CABI Agriculture and Bioscience,* 4, 3, https://doi.org/10.1186/s43170-023-00145-7

Silva A.M., Preto M., Grosso C., Vieira M., Delerue-Matos C., Vasconcelos V., Reis M., Barros L., Martins R. (2023), Tracing the path between mushrooms and Alzheimer's disease — A literature review. *Molecules,* 28(14), 5614, https://doi.org/10.3390/molecules28145614

Stabnikova O., Wang J.Y., Ivanov V. (2010), Value-added biotechnological products from organic wastes, In: L.K. Wang, V. Ivanov, J.H. Tay, Y.T. Hung (Eds.), *Handbook of Environmental Engineering, Environmental Biotechnology* Humana Press, NJ, pp. 343– 394, https://doi.org/10.1007/978-1-60327-140-0_8

Stabnikova O., Paredes-López O. (2023), Plant materials for the production of functional foods for weight management and obesity prevention. *Current Nutrition & Food Science*, 20, pp. 401-422, https://doi.org/10.2174/1573401319666230705110854

Statista. (2023), Global production of mushrooms and truffles 2012-2021, Available on line at 13.08.2023: Global production of mushrooms and truffles 2012-2021.

Stefaniak O., Dobrzyńska M., Drzymała-Czyż S., Przysławski J. (2022), Diet in the prevention of Alzheimer's disease: Current knowledge and future research requirements, *Nutrients,* 4(21), 4564, https://doi.org/10.3390/nu14214564

Straatsma G., Gerrits J.PG, Thissen J.T.N.M., Amsing J.G.M., Loeffen H., van Griensven L.J.L.D. (2000), Adjustment of the composting process for mushroom cultivation based on initial substrate composition, *Bioresource Technology,* 72(1), pp. 67-74, https://doi.org/10.1016/S0960-8524(99)00088-7

Sun S., Zhang X., Chen X., Zhang L., Zhu H. (2016), Production of natural edible melanin by *Auricularia auricular* and its physicochemical properties, *Food Chemistry,* 196, pp. 486–492, https://doi.org/10.1016/j.foodchem.2015.09.069

Supramani S., Rejab N.A., Ilham Z., Ahmad R., Show P.L., Ibrahim M.F., Wan-Mohtar W.A.A.Q.I. (2023), Performance of biomass and exopolysaccharide production from the medicinal mushroom *Ganoderma lucidum* in a new fabricated air-l-shaped bioreactor (ALSB), *Processes,* 11(3), 670, https://doi.org/10.3390/pr11030670

Szychowski K.A., Skóra B., Pomianek T., Gmiński J. (2021), *Inonotus obliquus* – from folk medicine to clinical use, *Journal of Traditional and Complementary Medicine,* 11(4), pp. 293-302, https://doi.org/10.1016/j.jtcme.2020.08.003

Straus L.G., González Morales M.R., Carretero J.M., Marín-Arroyo A.B. (2015), “The Red Lady of El Mirón”. Lower Magdalenian life and death in Oldest Dryas Cantabrian Spain: An overview, *Journal of Archaeological Science,* 60, 134–137, https://doi.org/10.1016/j.jas.2015.02.034

Tang W., Gao Y., Chen G., Gao H., Dai X., Ye J., Chan E., Huang M., Zhou S. (2005), A randomized, double-blind and placebo-controlled study of a *Ganoderma lucidum* polysaccharide extract in neurasthenia, *Journal of Medicinal Food,* 8(1), pp. 53-58, https://doi.org/10.1089/jmf.2005.8.53

Tang Y.J., Liu R.S., Li H.M. (2015), Current progress on truffle submerged fermentation: a promising alternative to its fruiting bodies, *Applied Microbiology and Biotechnology,* 99(5), pp. 2041-2053, https://doi.org/10.1007/s00253-015-6379-6

Teichmann A., Dutta P.C., Staffas A., Jägerstad M. (2007), Sterol and vitamin D2 concentrations in cultivated and wild grown mushrooms: Effects of UV irradiation, *LWT – Food Science and Technology,* 40(5), pp. 815–822, https://doi.org/10.1016/j.lwt.2006.04.003

Thakur M.P., Singh H.K. (2013), Mushrooms, their bioactive compounds and medicinal uses: A review, *Medicinal Plants – International Journal of Phytomedicines and Related Industries,* 5, pp. 1–20, https://doi.org/10.5958/j.0975-6892.5.1.004

Thorn R.G., Banwell A., Pham,T.H., Vidal N.P., Manful C.F., Nadeem M., Ivanov A.G., Szyszka Mroz B., Bonneville M.B., Hüner N.P.A., Piercey-Normore M.D., Thomas R. (2021), Identification and analyses of the chemical composition of a naturally occurring albino mutant chanterelle, *Scientific Reports,* 11(1), 20590, https://doi.org/10.1038/s41598-021-99787-8

Tibuhwa D.D. (2013), Wild mushroom- an underutilized healthy food resource and income generator: experience from Tanzania rural areas, *Journal of Ethnobiology and Ethnomedicine*, 9, 49, https://doi.org/10.1186/1746-4269-9-49

Tomao A., Bonet J.A., Martínez de Aragón J., de-Miguel S. (2017), Is silviculture able to enhance wild forest mushroom resources? Current knowledge and future perspectives, *Forest Ecology and Management,* 402, pp. 102–114, https://doi.org/10.1016/j.foreco.2017.07.039

Trivelli Tartufi. (2023), Truffle price: cost per kg and truffle exchange, Available online 14.08.2023. https://www.trivellitartufi.it/truffle-price/?lang=en)

Tsai M.Y., Hung Y.C., Chen Y.H., Chen Y.H., Huang Y.C., Kao C.W., Su Y.L., Chiu H.H.E., Rau K.M. (2016), A preliminary randomised controlled study of short-term *Antrodia Cinnamomea* treatment combined with chemotherapy for patients with advanced cancer, *BMC Complementary and Alternative Medicine,* 16, 322.

Valadares F., Garbi Novaes M.R., Cañete R. (2013), Effect of *Agaricus sylvaticus* supplementation on nutritional status and adverse events of chemotherapy of breast cancer: A randomized, placebo-controlled, double-blind clinical trial, *Indian Journal of Pharmacology,* 45(3), pp. 217-222, https://doi.org/ 10.4103/0253-7613.111894

Valdez-Morales M., Barry K., Fahey G.C., Domínguez J., de Mejia E.G., Valverde M.E., Paredes-López O. (2010), Effect of maize genotype, developmental stage, and cooking process on the nutraceutical potential of huitlacoche (*Ustilago maydis*), *Food Chemistry,* 119(2), pp. 689–697, https://doi.org/10.1016/j.foodchem.2009.07.0

Valverde M.E., Paredes-López O. (1993), Production and evaluation of some food properties of huitlacoche (*Ustilago maydis*), *Food Biotechnology,* 7(3), pp. 207-219, https://doi.org/10.1080/08905439309549858

Valverde M.E., Paredes-López O., Pataky J.K., Guevara-Lara F., Pineda T.S. (1995), Huitlacoche (*Ustilago maydis*) as a food source — biology, composition, and production. *Critical Reviews in Food Science and Nutrition,* 35(3), pp. 191–229, https://doi.org/10.1080/10408399509527699

Valverde M.E., Hernández-Pérez T., Paredes-López O. (2015), Edible mushrooms: Improving human health and promoting quality life, *International Journal of Microbiology,* 2015, 376387, https://doi.org/10.1155/2015/376387

Vaz J.A., Barros L., Martins A., Morais J.S., Vasconcelos M.H., Ferreira I.C.F.R. (2011), Phenolic profile of seventeen Portuguese wild mushrooms, *LWT – Food Science and Technology,* 44(1), pp. 343–346, https://doi.org/10.1016/j.lwt.2010.06.029

Venturella G., Ferraro V., Cirlincione F., Gargano M.L. (2021), Medicinal mushrooms: Bioactive compounds, use, and clinical trials, *International Journal of Molecular Sciences,* 22(2), 634, https://doi.org/ 10.3390/ijms22020634

Vetter J. (2003), Data on sodium content of common edible mushrooms, *Food Chemistry,* 81(4), pp. 589-593, https://doi.org/10.1016/S0308-8146(02)00501-0

Yoshimura K., Kamot, T., Ogaw, O., Matsu, S., Tsuchiy, N., Tad, H., Murat, K., Yoshimur, K., Habuchi T., Fukushim, M. (2010), Medical mushrooms used for biochemical failure after radical treatment for prostate cancer: An open-label study, *International Journal of Urology,* 17(6), pp. 548-554, https://doi.org/10.1111/j.1442-2042.2010.02528.x

Wachtel-Galor S., Yuen J., Buswell J.A., Benzie I.F.F. (2011), *Ganoderma lucidum* (Lingzhi or Reishi): A medicinal mushroom. In: I.F.F. Benzie, S. Wachtel-Galor

(Eds.), *Herbal Medicine: Biomolecular and Clinical Aspects,* Boca Raton (FL), CRC Press/Taylor & Francis.

Watling R. (1997), The business of fructification, *Nature,* 385, pp. 299–300, https://doi.org/10.1038/385299a0

Wang H., Fu Z., Han C. (2013), The medicinal values of culinary-medicinal royal sun mushroom (*Agaricus blazei* Murrill), *Evidence-Based Complementary and Alternative Medicine,* 2013, 842619, https://doi.org/ 10.1155/2013/842619

Wang F., Xu L., Zhao L., Ding Z., Ma H., Terry N. (2019), Fungal laccase production from lignocellulosic agricultural wastes by solid-state fermentation: A review, *Microorganisms,* 7(12), 665, https://doi.org/10.3390/microorganisms7120665

Wasser S.P. (2010), Medicinal mushroom science: history, current status, future trends, and unsolved problems, *International Journal of Medicinal Mushrooms,* 12(1), pp. 1–16, https://sci-hub.se/10.1007/s00253-010-3067-4

Wasser S.P. (2011), Current findings, future trends, and unsolved problems in studies of medicinal mushrooms, *Applied Microbiology and Biotechnology,* 89, pp. 1323-1332, https://doi.org/10.1007/s00253-010-3067-4

Watanabe F., Schwarz J., Takenaka S., Miyamoto E., Ohishi N., Nelle E., Hochstrasser R., Yabuta Y. (2012), Characterization of vitamin B12 compounds in the wild edible mushrooms black trumpet (*Craterellus cornucopioides*) and golden chanterelle (*Cantharellus cibarius*), *Journal of Nutritional Science and Vitaminology,* 58(6), pp. 438–441, https://doi.org/10.3177/jnsv.58.438

Watanabe F., Yabuta Y., Bito T., Teng F. (2014), Vitamin B_{12}-containing plant food sources for vegetarians, *Nutrients,* 6(5), p. 1861-1873, https://doi.org/10.3390/nu6051861

Weichselbaum E., Benelam B., Soares Costa H. (2009), Synthesis report No 6 traditional foods in Europe, EuroFIR Project Management Office/British Nutrition Foundation, Norwich, UK.

Witkowska A.M., Zujko M.E., Mirończuk-Chodakowska I. (2011), Comparative study of wild edible mushrooms as sources of antioxidants, International *Journal of Medicinal Mushrooms,* 13(4), pp. 335-341, https://doi.org/10.1615/intjmedmushr.v13.i4.30

Xiang Y., Xu X., Li J. (2012), Chemical properties and antioxidant activity of exopolysaccharides fractions from mycelial culture of *Inonotus obliquus* in a ground corn stover medium, *Food Chemistry,* 134(4), 1899e1905, https://doi.org/10.1016/j.foodchem.2012.03.121

Xu Z., Fu L., Feng S., Yuan M., Huang Y., Liao J., Zhou L., Yang H., Ding C. (2019), Chemical composition, antioxidant and antihyperglycemic activities of the wild *Lactarius deliciosus* from China, *Molecules,* 24(7), 1357, https://doi.org/10.3390/molecules24071357

Yusufov M., Weyandt, L.L., & Piryatinsky, I. (2017). Alzheimer's disease and diet: a systematic review. *International Journal of Neuroscience, 127*(2), 161-175. https://doi.org/10.3109/00207454.2016.1155572.

Zhang Y., Venkitasamy C., Pan Z., Wang W. (2013), Recent developments on umami ingredients of edible mushrooms—A review, *Trends in Food Science and Technology,* 33, pp. 78–92, https://doi.org/10.1016/j.tifs.2013.08.002

Zhang B.B., Guan Y.Y., Hu P.F., Chen L., Xu G.R., Liu L., Cheung P.C.K. (2019), Production of bioactive metabolites by submerged fermentation of the medicinal mushroom *Antrodia cinnamomea*: Recent advances and future development, *Critical Reviews in Biotechnology,* 39(4), pp. 541-554, https://doi.org/10.1080/07388551.2019.1577798

Zhao H., Zhang Q., Zhao L., Huang X., Wang J., Kang X. (2012), Spore powder of *Ganoderma lucidum* improves cancer related fatigue in breast cancer patients undergoing endocrine therapy: A pilot clinical trial, *Evidence Based Complementary and Alternative Medicine, 2012*, 809614, https://doi.org/10.1155/2012/809614

Zhao W., Xu J.W., Zhong J.J. (2011), Enhanced production of ganoderic acids in static liquid culture of *Ganoderma lucidum* under nitrogen-limiting conditions. *Bioresource Technology,* 102(17), pp. 8185–8190, https://doi.org/10.1016/j.biortech.2011.06.043

Zhao Y., Wang L., Zhang D., Li R., Cheng T., Zhang Y., Liu X., Wong G., Tang Y., Wang H.J.S.R. (2019), Comparative transcriptome analysis reveals relationship of three major domesticated varieties of *Auricularia auricula-judae*, *Scientific Reports,* 9, 78, https://doi.org/10.1038/s41598-018-36984-y

Cite:

UFJ Style

Stabnikova O., Stabnikov V., Paredes-López O. (2023), Wild and cultivated mushrooms as food, pharmaceutical and industrial products, *Ukrainian Food Journal*, 13(1), pp. 20–59, https://doi.org/10.24263/2304-974X-2024-13-1-4

APA Style

Stabnikova, O., Stabnikov, V., & Paredes-López, O. (2023). Wild and cultivated mushrooms as food, pharmaceutical and industrial products. *Ukrainian Food Journal, 13*(1), 20–59. https://doi.org/10.24263/2304-974X-2024-13-1-4