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Composition and Biological Properties of *Agaricus bisporus* Fruiting Bodies – a Review

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White *Agaricus bisporus* is both the most popular and the most commonly eaten edible mushroom species in the world. It is popular not only because of its taste, but also due to its high level of nutrients: dietary fiber (chitin), essential, semi-essential amino acids, unsaturated fatty acids including linoleic and linolenic acids, easily digestible proteins, sterols, phenolic and indole compounds, and vitamins − especially provitamin D_2 and B_1, B_2, B_6, B_7, and C. Fruiting bodies of *A. bisporus* have antioxidant, antibacterial, anti-inflammatory, antitumor, and immunomodulatory activity. The presence of antioxidant ergothioneine (which also displays the antimutagenic, chemo- and radioprotective activity) is also noteworthy. *A. bisporus* also contains derivatives of benzoquinone, a substance which belongs to the group of antibiotics. Studies of tyrosinase isolated from this species show its very high similarity to human tyrosinase. This points directly to the fact that this species could be a rich source of tyrosinase used for medicinal and cosmetics purposes. *A. bisporus* is also a rich source of selenium, zinc and other elements such as magnesium, copper, iron, potassium, sodium, calcium, phosphorus, sulfur or manganese. In conclusion, the presence of these compounds and elements with biological activity in fruiting bodies of *A. bisporus* confirms their nutraceutical and medicinal properties.

INTRODUCTION

Mushrooms have a scientifically confirmed beneficial influence on human health. This property stretches beyond that which can be expected from nutrients found in mushrooms. Based upon the chemical composition of edible mushroom fruiting bodies, it can be stated that they are a valuable source of dietary ingredients necessary for stimulating the development and growth of the human organism and sustaining its life functions. *Agaricus bisporus* (J.E. Lange) Imbach – white or button mushroom, is mainly available for consumers from commercial cultures; it is well known for its taste and aroma. The most important qualities of *A. bisporus* are its dietetic and medicinal properties derived from its rich composition of metabolites and biologically-active elements. *A. bisporus* is a rich source of dietary fiber (chitin), essential and semi-essential amino acids, and antioxidant substances (sterols, phenolic and indole compounds, ergothioneine, vitamins, selenium) [Elmastas *et al*., 2007; Foulongne-Orio *et al.*, 2013].

A. bisporus grows in Poland between May and September. Usually, it occurs in places fertilized with cow dung, compost piles, parks and forests. Its growth on open spaces is rare. More frequently, it can be cultivated on special culturing substrates [Leiva *et al.*, 2015]. *A. bisporus* plays an important part in the decomposition of leaves and needles in parks and forests. Apart from its ecological function, it is one of the most frequently cultivated mushrooms worldwide. The first known information about *A. bisporus* culturing comes from France in 1707 [Elmastas *et al.*, 2007; Foulongne-Orio *et al.*, 2013; Glamočlija *et al.*, 2015] and for this reason, the species is also widely known as the Paris champignon.

The aim of the present study was to describe the importance, dietary value, and medicinal properties of *A. bisporus* fruiting bodies.

THE MAIN GROUPS OF BIOLOGICALLY-ACTIVE SUBSTANCES IN *AGARICUS BISPORUS*

Amino acids in fruiting bodies of *Agaricus bisporus*

Fruiting bodies of *A. bisporus* are a rich source of amino acids (essential, semi-essential, and non-essential). Eighteen of these compounds were researched and described, but some are not present in sufficiently high amounts to make *A. bisporus* a source for supplementation. The amino acids found in *A. bisporus* in the highest amounts are alanine, aspartic acid, glutamic acid, arginine, leucine, lysine, phenylalanine, serine, proline, tyrosine and threonine [Bernaś *et al.*, 2006a; Muszyńska *et al.*, 2013a]. On the other hand, cysteine, methionine and valine are the least abundant [Bernaś *et al*. 2006b]. Liu *et al*. [2013] determined the total content of free amino acids as 70.55 mg/g dry weight (D.W.). Arginine pres-

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ent in the *Agaricales* taxon should be given special attention – because it is a component used in dietary supplements for patients with cancer. Arginine delays tumor growth and metastasis, and also has a beneficial influence on the immunological system, body mass growth and the life-expectancy of oncological patients [Novaes *et al*., 2011]. In further research, it was shown that the processes of production and storage (the most popular are drying, preserving in air tight containers, salting and freezing) of *A. bisporus* decrease the total content of amino acids in this species. The decrease in amino acid concentrations after six months of storage ranged between 40% and 90% and depended on the processing method [Bernaś *et al.*, 2006b]. Pei *et al.* [2014] determined free amino acids in fruiting bodies of *A. bisporus* and their content ranged from 0.8 to 14.1 mg/g D.W. The total content of free amino acids was up to 44.2 mg/g D.W. [Pei *et al*., 2014]. The detailed information is to be found in Table 1.

Saccharides in *Agaricus bisporus* fruiting bodies

Mushrooms are characterized by high contents of monosaccharides, disaccharides and polysaccharides. Research has shown that the total content of carbohydrates in fruiting bodies of white mushroom ranges between 4.5 and 4.6% of fresh weight or 51.3 and 62.5% dry weight (Table 1). *A. bisporus* is also a rich source of fiber which beneficially affects the digestive tract. Although the cell walls of plants are usually considered a main source of dietary fiber – mushrooms can also assume this function. Mushroom cell walls contain a mixture of fibers and matrix components that are rich in chitin (a cross-linked polymer of N-acetylglucosamine) and other polysaccharides such as β-D-glucans and mannans [Cheung, 2013; Liu *et al.*, 2013]. Apart from its role in the metabolism, dietary fiber from mushrooms plays an important role in the regulation of lipid levels, and decreasing levels of low density lipoprotein (LDL) and total cholesterol without interfering with high density lipoprotein concentrations (HDL) [Cheung, 2013; Muszyńska *et al*., 2013a; Rajewska & Bałasinska, 2004]. The mechanism of this phenomenon is not entirely clear, but it has been proven that the fiber from mushrooms can be an alternative to that originating from other foodstuffs. A hypocholesterolemic effect can be caused by impaired absorption in the digestive tract due to dietary fiber presence, or by the influence of intestinal or pancreatic secretion. Other possible mechanisms include an indirect influence on lipoproteins or the bile acid metabolism. Considering a high content of dietary fiber and a low content of fat, *A. bisporus* may become a dietary component that prevents atherosclerosis [Fukushima *et al.*, 2000]. Chitin and chitosan are commonly used in the pharmaceutical industry. Apart from being adjuvant in many drugs, these substances are ingredients of many slimming preparations. The slimming effect occurs due to decreased absorption of lipids from food. The efficacy of chitosan was researched with two groups of volunteers on a low fat diet. Patients regularly taking chitosan reduced their weight considerably more quicker. The chitosan group lost, on average, 7 kg and the patients from the control group lost only 3 kg [Rajewska & Bałasińska, 2004]. Apart from a beneficial influence on fat metabolism and body weight decrease, the research also showed an improvement in sugar metabolism. Consumption of *A. bisporus* caused a 24.7% decrease in glucose levels in type II diabetic rats. A similar positive effect was obtained in rats with hypercholesterolemia, in which a decrease in LDL and total cholesterol was noted as well as an increase in HDL cholesterol fraction [Czapski, 2005; Jeong *et al.*, 2010].

Apart from their antimicrobial activity, chitin and chitosan are also used in wound dressings. Their action involves local pain relief (due to separating pain receptors from environmental exposure), wound healing enhancement and prevention of scaring [Rajewska & Bałasinska, 2004]. An important property of chitosan – its blood clotting ability – has been used in hemorrhaging wound dressings. Chitosan can work without setting up a normal blood clotting cascade. Unfortunately, its effectiveness has been questioned due to its low adhesion abilities. New animal trials suggest that modified chitosan with higher bioadhesive abilities will be significantly more effective in wound treatment [De Castro *et al.*, 2012]. Currently, dressings based on chitosan are used in military medicine – even for very severe combat injuries. Chitosan-based dressings were used by the US army during the Iraqi intervention. There have been promising results from new experiments into the use of chitosan in dental surgery where parts of military dressings were used for hemorrhages during teeth extraction [Bennett & Littlejohn, 2014; Malmquist *et al.*, 2008].

Trehalose, a disaccharide found in *A. bisporus* (with the content ranging from 1% to 3% D.W.), is metabolized to glucose in the human organism. It stimulates enzymes responsible for the stabilization of protein structures during chemical and thermal denaturation. In mushrooms, trehalose acts as a carbohydrate reservoir and protects the mushroom from extreme environmental conditions such as temperatures, osmotic stress or radiation. Mushrooms are also rich in sugar alcohols such as mannitol (5–30% D.W.) [Gheibi *et al.*, 2006; Malmquist *et al*., 2008; Wannet *et al*., 1998]. Pei *et al.* [2014] found the content of mannitol in fresh fruiting bodies at 121 mg/g and that for trehalose at 12.1 mg/g. These researchers examined whether the freeze drying influenced the level of these compounds and found decreased contents of these sugars after the freeze drying process.

Fucogalactan from *A. bisporus* (EFP-Ab) presented a new class of mushroom metabolites with anti-inflammatory activity as a result of suppressed iNOS and COX-2 expression [Ruthes *et al*., 2013].

A. bisporus contains a linear (1→6)-β-d-glucan that can be isolated by DMSO extraction. This compound inhibits the expression of pro-inflammatory genes and reduces LPS-induced inflammation by inhibition of IL-1 and COX-2 proteins [Smiderle *et al*., 2013].

Lectins from fruiting bodies of *A. bisporus* and their antiproliferative activity

Lectins are the next group of therapeutically-active compounds found in *A. bisporus* fruiting bodies and mycelium from *in vitro* cultures. Lectins are conjugates of proteins (mainly storage proteins) and saccharides produced by mushrooms and plants. It has been proven that the role of lectins is more complicated in mushrooms than in plants [Hassan *et al*., 2015]. These substances are involved in numerous processes on a molecular and cell level. In higher mushroom species such as the white mushroom, lectins may play various roles depending on growth phase or environmental conditions. Lectins are storage proteins intervening in growth, development and morphogenesis phases. Some are involved in important functions of mushroom metabolism such as mycorrhiza or parasitic dependencies with other organisms. Lectins may protect the mushrooms from toxins coming from the environment, such as pesticides or bacteria [Ng, 2004]. Lectins, particularly those from edible mushrooms, have attracted the attention of the academic community, because their immunomodulatory activity comes from an acceleration of immunological cell maturation and a potential anticancer activity. The anticancer effect is possible due to the anti-proliferative influence of lectins of *A. bisporus* (ABL) on endothelial carcinoma cells, without inducing the cytotoxic effect [Carrizo *et al*., 2005; Singh *et al*., 2015]. Lectins from *A. bisporus* are also capable of inhibiting the reverse transcriptase of HIV1, which stops virus replication in host cells [Wang & Ng, 2001]. ABL have been researched as active compounds in psoriasis (because it is a disease originating from excessive proliferation of human keratocytes) [Yu *et al*., 1999]. Application of lectins stops further cell divisions without any cytotoxic effect on endothelium cells [Parslew *et al*., 1999]. Lectins have also been examined as active in vitreoretinopathy and other eye diseases involving wound healing impairment. The ABL slow retina contractions and adhesion of human pigmentation cells to retina endothelium, also without any cytotoxic effect. During clinical trials, lectins have shown strong anti-proliferative action against epithelial cells of the retina, which could directly reduce retinal detachment [Kent *et al*., 2003ab; Wang *et al*., 2012]. The ABL show the anti-proliferative action towards numerous types of cells. One *in vitro* experiment was conducted to confirm the inhibitory effect of ABL on fibroblasts found in the Tennon capsule. An increase in wound healing was shown, which furthermore led to the application of ABL in controlling scaring after surgical glaucoma treatment [Batterbury *et al*., 2002]. Lectins have also been examined as potentially anti-diabetic substances effective both in prophylaxis and treatment. This effect comes from lectins capability to enhance the divisions of β cells in pancreatic islets. Some studies have been performed to determine the degree of regeneration on β cells in mice and to describe the mechanisms of their proliferation. The analysis was conducted based on glucose measurements and insulin secretion levels after administration of mushroom lectins. It was shown that lectins from *A. bisporus* decreased blood glucose levels [Ahmad *et al*., 1984; Jeong *et al*., 2010].

Indole compounds in fruiting bodies of *Agaricus bisporus*

Recent research has proven that *A. bisporus* contains non-hallucinogenic indole compounds [Muszyńska *et al*., 2015a, b]. Indole compounds have a beneficial influence on the human organism and play an important role in numerous metabolic pathways – as neurotransmitters or their precursors. Indoles are important compounds due to their anti-cancer and anti-aging activity; these compounds regulate cell cycles and blood clotting. The pharmacological profile of these compounds also includes their antioxidant activity. The fruiting bodies of *A. bisporus* contain L-tryptophan, 5-hydroxy-L-tryptophan, melatonin, serotonin, tryptamine, and 5-methyl-tryptamine [Muszyńska *et al*., 2013b]. The research conducted by Muszyńska describes the amount of indole compounds extracted from *A. bisporus* to artificial gastric juice. This research showed how much of each indole compound is released from white mushroom fruiting bodies or *in vitro* cultures in the conditions of the human digestive tract. The fruiting bodies were obtained from a commercial source and the *in vitro* cultures from liquid cultures on Oddoux medium (both standard and enriched in zinc hydroaspartate). Four indole compounds were identified and assayed: 5-hydroxy-L-tryptophan, L-tryptophan, serotonin, and 5-methyl-tryptamine. *A. bisporus* could be a good source of indole compounds [Muszyńska *et al*., 2015a, b]. The contents of indole compounds in fruiting bodies range from 0.06 to 6.21 mg/100 g D.W. (Table1). The highest content has been reported for kynurenic acid [Muszyńska *et al*., 2011].

Phenolic compounds in fruiting bodies of *Agaricus bisporus*

Phenolic acids are the major representatives of the phenol compounds present in mushrooms. They exhibit a wide spectrum of biological activities which have been attributed to their strong antioxidant activity and ability to protect vital cellular structures, such as cell membranes, and also structural proteins, enzymes, membrane lipids or nucleic acids. Gallic, caffeic, ferulic, *p*-coumaric, and protocatechuic acids are found in fruiting bodies of *A. bisporus*. They are characterized by antioxidant, antibacterial, antiviral, antifungal, anti-inflammatory, and gastric-secretion stimulatory actions, documented by *in vitro* and *in vivo* studies [Czapski, 2005; Labus *et al*., 2011; Liu *et al*., 2013]. In addition, protocatechuic acid has been shown to possess immunomodulating, spasmolytic, cardioprotectant, anticoagulant, and chemopreventive properties [Wee, 2010]. The contents of phenolic compounds in fruiting bodies of *A. bisporus* range from 2.31 mg/kg D.W. for *p*-coumaric acid to 2729 mg/kg D.W. for myricetin [Czapski, 2005; Labus *et al*., 2011; Liu *et al*., 2013]. A positive correlation between microbial inhibitions and the total content of phenolic compounds in ethanol extracts from fruiting bodies of *A. bisporus* was presented in an Australian research [Ndungutse *et al*., 2015]. The content of phenolic compounds in *A. bisporus* fruiting bodies is presented in Table 1.

Tyrosinase from fruiting bodies of *Agaricus bisporus* and its properties

The pharmacological properties and application of white mushrooms are connected with the process of melanogenesis in the human organism. Melanogenesis – the biosynthesis of the pigment melanin in the skin – is catalyzed by tyrosinase. Since the discovery of this enzyme, research has been undertaken in order to find a good natural source of this substance. It has been found that *A. bisporus* naturally contains large quantities of this compound. Tyrosinase acts as a catalyst in the hydroxylation of monophenol and the oxidation of diphenol in the presence of atmospheric oxygen [Kampmann *et al*., 2015; Labus *et al*., 2011; Zaidi *et al*., 2014]. It has also been shown that tyrosinase isolated from *A. bisporus* may catalyze bisphenol reactions, which could make this species a useful bioremediation agent [Kampmann *et al*., 2015]. Tyrosinase plays an important role in the synthesis of melanin in melanocytes found in epidermis and cells from the neural crest. This enzyme was described for the first time in mammals [Bloch, 1927]. Its connection with the development of melanoma has been described, as well as its link to skin pigmentation problems (such as vitiligo or albinism) [Zaidi *et al*., 2014]. Tyrosinase can be extracted from various sources, *i.e.* mushrooms and fruits. In mushrooms, melanin is involved in numerous defense mechanisms that protect mushrooms from various stress factors such as UV or gamma radiation, free radicals, dehydration or extreme temperatures. The stability of mushroom spores is also derived from the protective action of melanin. Furthermore, tyrosinase has a role in wound healing and immunological response in plants. In humans, tyrosinase is involved in melanocyte pigmentation processes; it is also a marker in melanoma patients and takes part in the prodrug metabolism [Labus *et al*., 2011; Zaidi *et al*., 2014]. Research on tyrosinase isolated from white mushrooms has shown a high similarity to human tyrosinase. It suggests that this species could be a rich source of tyrosinase for medicinal and cosmetic purposes [Labus *et al*., 2011; Zaidi *et al*., 2014]. Tyrosinase is a thermolabile protein. It shows a protective effect towards Raji cells (human lymphoma cell line), preventing oxidative DNA damage. *A. bisporus* species shows a protective effect to DNA isolated from lymphocytes taken from rats into which mushroom extracts have been injected intraperitoneally. The genoprotective effect of tyrosinase has been determined by gel electrophoresis of single cells and cell damage extent after application of stress generating factors was evaluated. In the test, enzymatic hydroxylation of tyrosine occurred, leading to levodopa and then a conversion to dopaquinone. The protective potential of oxidative damage depends on tyrosinase, which is a first link in the tyrosine reaction pathway. This is not an effect of oxidant inactivation but levodopa conversion, which is possible due to the catalytic action of *A. bisporus* tyrosinase [Shi *et al*., 2002].

Ergothioneine in fruiting bodies of *Agaricus bisporus* and their antioxidant activity

The antioxidant action of *A. bisporus* is connected with a histidine derivative – ergothioneine. Ergothioneine is a water-soluble compound found in some mycobacteria and molds and it is not synthesized by animals, in which it is important for proper functioning. These organisms easily absorb ergothioneine and store it in cells that are especially susceptible to oxidative stress. The highest amount of this substance can be found in erythrocytes, the eye lens, semen, and skin. Its most important feature is the ability to reduce lesions due to irradiation, hypoxia (from transplantations), heart attack or brain stroke. Ergothioneine is a key substrate for organic cation transporters (OCTN1) and plays a protective role for monocytes. A decreased level of these cells and their improper differentiation is characteristic for auto-immunological diseases such as rheumatoid arthritis or Crohn's disease. Apart from its antioxidant action, ergothioneine also shows antimutagenic, chemo- and radioprotective activity, which makes it an important medical substance [Chen *et al.,* 2012; Muszyńska *et al*., 2013a]. The content of ergothioneine found in fruiting bodies of *A. bisporus* by Dubost *et al*. [2007] was at 0.21 mg/g D.W. Chen *et al*. [2012] stated that the content of this compound was higher and reached up to 0.93 mg/g D.W. These data show that *A. bisporus* is one of the best sources of this compound [Chen *et al*., 2012].

Fruiting bodies of *A. bisporus* as a source of lovastain

One of the most significant compounds found in fruiting bodies of *A. bisporus* is lovastatin — an approved-to-market drug used in the treatment of hypercholesterolemia — that acts as an inhibitor of HMG-CoA reductase. The highest content of lovastatin (565.4 mg/kg D.W.) has been found in fruiting bodies of mature mushrooms [Chen *et al*., 2012].

Fruiting bodies of *A. bisporus* as a source of agaritine

Agaritine has been claimed to be a weak carcinogen. It was shown to induce adenomas and adenocarcinomas in the lungs and to cause bladder and stomach cancer in mice [Kondo *et al*., 2008]. Agaritine content decreases during preservation. Storage at 5^{o}C reduced its content to 25% and 50% after 6 and 14 days, respectively [Schulzová *et al*., 2002]. However, this compound displays the antiviral activity, *e.g.* as a potent inhibitor of HIV protease [Sorimachi & Koge, 2008].

Fruiting bodies of *Agaricus bisporus* as a source of vitamins

White mushroom is a rich source of vitamins, especially the B-group vitamins (B_1, B_2, B_3, niacin, folates, B_{12}), and vitamin D_2 – provitamin ergosterol, and ergocalciferol [Kalbarczyk & Radzki, 2009]. This species is also a good source of vitamin C (17 mg/100 g D.W.) [Bernaś *et al*., 2006b; Kalbarczyk & Radzki, 2009]. The content of vitamins varies depending on mushroom growing conditions (including environmental factors). *A. bisporus* contains ergosterol – a precursor of vitamin D_2 (ergocalciferol), which is necessary for sustaining the appropriate calcium-phosphate balance in the human organism. Ergosterol content in fruiting bodies of *A. bisporus* is usually reported to range from 61.5 mg/100 g of D.W. [Muszyńska *et al*., 2013a] to 186.1 mg/100 g D.W. [Heleno *et al*., 2016]. The high levels of this substance make white mushroom a rich source of vitamin D for vegetarians and vegans [Muszyńska *et al*., 2013a]. There have been experiments designed to enrich *A. bisporus* with vitamin D_2 *via* irradiation with UV-B and UV-C light [Koyalamudi *et al*., 2009; Roberts *et al*., 2008]. Their results seem to be promising in the prevention of common vitamin D deficiencies, including in Poland. Detailed information about the content of vitamins in fruiting bodies of *A. bisporus* is presented in Table 1.

Fruiting bodies of *A. bisporus* as a source of macro- and microelements

The fact that mushrooms are able to accumulate elements from the environment explains their attractiveness for researchers. Bioelements that are absorbed by some mushroom species

TABLE 1. Content of biologically-active substances in *A. bisporus* fruiting bodies.

Group	Examples	Content	Reference
Amino acids		(mg/g D.W.)	[Bernaś *et al*., 2006b] [Pei *et al*., 2014]
	Total amino acids	44.2	
	Lysine	3.5	
	Threonine	1.3	
	Valine	2.3	
	Methionine	0.8	
	Isoleucine	1.0	
	Leucine	0.8	
	Phenylalanine	2.1	
	Arginine	2.2	
	Glycine	2.0	
	Histidine	14.1	
	Asparagine acid	3.4	
	Glutamate acid	5.6	
	Serine	3.1	
		(g/100 g total proteins in F.W.)	
	Cysteine	1.1	
	Tyrosine	4.2	
	Alanine	5.8	
	Proline	6.1	
Carbohydrates		(g/100 g F.W.)	[Gheibi *et al*., 2006] [Kalbarczyk & Radzki, 2009]
	Total sugar	4.50	
	Fructose	2.62	
	Mannitol	23.62	
		(%/D.W.)	
	Trehalose	1–3	
Indole compounds		(mg/100 g D.W.)	[Muszyńska *et al*., 2011]
	L-Tryptophan	0.39	
	Serotonin	5.21	
	Melatonin	0.11	
	Tryptamine	0.06	
	Kynurenic acid	6.21	
	Indoloacetic acid	0.19	
Phenolic compounds		(mg/kg D.W.)	[Czapski, 2005] [Labus *et al*., 2011] [Liu *et al*., 2013] [Reis *et al*., 2012]
	Free phenols	176–487	
	Total phenols	277–687	
		(mg/kg D.W.)	
	Gallic acid	280.45	
	Procatechuic acid	83.26	
	Catechins	56.74	
	Caffeic acid	392.51	
	Ferulic acid	42.83	
	Myricetin	2729.46	
	p-Coumaric acid	2.31	
	Cinnamic acid	0.38 mg/kg D.W.	
Fatty acids		(mg/100 g D.W.)	[Öztürk *et al*., 2011]
	Total lipids	2.7	
		(%)	
	Caprylic acid	1.08	
	Caprinic acid	0.85	
	Laurnic acid	0.11	
	Miristic acid	0.94	
	Pentadecanoic acid	0.23	
	Palmitynic acid	13.35	
	Palmitoleic acid	4.84	
	Stearic acid	3.72	
	Oleic acid	6.07	
	Linoleic acid	67.29	
	Linolenic acid	1.52	
	Arachidic acid	0.92	
	Total saturated fatty acids	20.28	
	Total unsaturated fatty acids	79.72	
Vitamins		(mg/100 g D.W.)	[Bernaś *et al*., 2006b] [Kalbarczyk & Radzki, 2009]
	Vitamin C	17.0	
	Vitamin B_1	0.6	
	Vitamin B_2	5.1	
	Vitamin B_3	43.0	
	Niacin	42.0	
		(μg/100 g D.W.)	
	Folic acid	450	
	Vitamin	0.8	
	B_{12} Vitamin D	3.0	
Tocopherol		(mg/100 g)	[Tsai *et al*., 2008]
	α-Tocopherol	1–4	
	γ-Tocopherol	2–3	
	δ-Tocopherol	1	
Sterols		(mg/100 g D.W.)	[Heleno *et al*., 2016] [Muszyńska *et al*., 2013a]
	Ergosterol	186.1	
	Ergosta-7-enol	1.73	
	Ergosta-5,7--dienol	6.05	
	Ergosta-7,22--dienol	2.45	
Elements		(mg/kg D.W.)	[Bernaś *et al*., 2006b] [Kalać, 2010] [Kalembasa *et al*., 2012] [Muszyńska *et al*., 2015b]
	Copper	25–125	
	Magnesium	1150.5–2275	
	Iron	200–400	
	Sodium	760 – 860	
	Potassium	35000–45200	
	Calcium	460–990	
	Phosphorus	9690–17300	
	Zinc	54.81–112.75	
	Lithium	17.1–36.9	
	Titanium	5.00–15.5	
	Barium	2.06–7.71	
	Strontium	0.015–0.037	
	Selenium	0.053–0.150	
	Cadmium	0.021–0.091	
	Lead	0.028–0.148	
	Chromium	0.344–0.640	
	Nickel	0.101–0.778	

D.W. – dry weight, F.W. fresh weight.

act as enzyme activators or are their structural parts. The most important mechanism of accumulation of elements in mushrooms is based on binding by metallothionein – a low-molecular-weight protein, which has an affinity especially for metals. Elements can also be found in mushroom dyes. Numerous researchers have also confirmed the presence of copper, magnesium, iron, sodium, potassium, calcium, phosphorus, zinc, lithium, titanium, barium, strontium, selenium, cadmium, lead, chromium, and nickel. The content of these elements is shown in Table 1. White mushroom is a rich source of selenium and zinc. These elements demonstrate antioxidant abilities, due to which mushrooms can prevent oxidation of unsaturated fatty acids. Selenium levels can be as high as 0.5 mg/100 g D.W. [Falandysz & Borovička, 2013; Yilmaz *et al*., 2006]. Zinc is vital for protein synthesis, an important component of digestive enzymes, and is involved in insulin storage and in the activation of more than 300 enzymes. According to the literature data, zinc content in fruiting bodies of *Agaricus* species ranges from 7.5 to 15 mg/100 g D.W. [Kalač, 2010]. The daily requirement for this element in a healthy adult human is dependent on age and is about 15 mg [Johnson, 2003]. The levels of zinc released from fruiting bodies and biomass from *in vitro* cultures of *A. bisporus* have been established. A maximum of 2 mg Zn/100 g D.W. are released from fruiting bodies of *A. bisporus* to artificial digestive juices, whereas the total amount of zinc released from biomass of *A. bisporus* obtained from *in vitro* culture averages 10 mg/100 g D.W. The highest total concentration of this element released into artificial digestive juices has been found in biomass of *A. bisporus* cultures on the culture medium with the addition of 200 mg/L zinc hydroaspartate (up to 57 mg/100 g D.W.) [Muszyńska *et al*., 2015a]. The levels of elements in extracts of fruiting bodies of *A. bisporus* are presented in Table 1.

BIOLOGICAL ACTIVITY OF FRUITING BODIES OF *AGARICUS BISPORUS*

Anti-carcinogenic and antioxidant properties of substances found in fruiting bodies of *A. bisporus*

Free radicals usually found in the human organism can lead to the development of many civilization diseases, such as cancer or cardiovascular disease. Oxidative stress and free radical production can be caused by diseases, long periods of stress or natural aging. There are internal natural mechanisms in the human organism that can prevent oxidative stress, such as the production of free radical species – superoxide dismutase (SOD) or catalase [Elmastas *et al*., 2007; Hu *et al*., 2015; Maseko *et al*., 2014; Tsai *et al*., 2008]. These natural mechanisms should be aided by providing antioxidants with food. As a source of antioxidants, *A. bisporus* has for many years been examined for the potential preventive action in hypertension, hypercholesterolemia or cancer [Elmastas *et al*., 2007; Tsai *et al*., 2008]. Due to their acetylcholinesterase and butyrylcholinesterase inhibiting activity, *A. bisporus* extracts can be potentially applied in Alzheimer's disease treatment [Öztürk *et al.,* 2011].

Apart from its occurrence in the natural environment, white mushroom is widely grown on organic substrates. Methanol extracts from this species have been examined for antioxidant activity derived from high concentrations of α-tocopherol and these have also revealed the presence of β-carotene [Tsai *et al*., 2008]. The antioxidant effect of *A. bisporus* is strongly correlated with substances found in this mushroom that act as reducers in many chemical reactions, and that are able to scavenge free radicals or chelate metal ions [Elmastas *et al*., 2007; Glamočlija *et al*., 2015; Vamanu & Nita, 2014]. The role of *A. bisporus* fruiting body extracts in the prevention of some cancer types such as breast cancer or prostate cancer has been researched and confirmed. The main substances responsible for this action are phenol compounds, lectins, β-glucans, arginine, ergothioneine and fatty acids (80% of total fatty acid amount are unsaturated fatty acids). This is important, because a deficiency in these substances in the diet can be the causative agent of many diseases, such as cancer or circulatory system diseases [Ahmad *et al*., 2013; Novaes *et al*., 2011; Öztürk *et al*., 2011; Patel & Goyal, 2012; Yilmaz *et al*., 2006].

A. bisporus is a rich source of fatty acids such as palmitic acid, linoleic acid, linolenic acid that can prevent the development of breast cancer [Öztürk *et al*., 2011]. This action involves inhibition of aromatase and consequently – synthesis of estrogens – hormones that play an important role in breast cancer development. The latest clinical research has shown that aromatase inhibitors are effective in hormone-dependent mammary cancer treatment [Patel & Goyal, 2012; Chen *et al*., 2006]. In research conducted by Chen *et al*. [2006], *A. bisporus* extracts were the most effective aromatase inhibitors, when compared with seven other plant extracts. Phenolic acids isolated from *A. bisporus*, including hydroxybenzoic acid and protocatechuic acid, are also characteristic for this species. These substances, apart from their typical anti-carcinogenic activity, also show antioxidant and anti-inflammatory actions [Siwulski *et al*., 2014]. The application of *A. bisporus* to anticancer therapy should, therefore, be feasible and inexpensive [Chen *et al*., 2006].

The anti-carcinogenic activity can also be observed for ergosterol found in the *Agaricales* taxon. This can provide anti-carcinogenic activity *via* inhibiting the metaplastic cell migration and proliferation. Ergosterol can also inhibit angiogenesis. In patients treated with ergosterol, a delay in tumor growth has been obtained along with minimal side effects. In patients under chemotherapy, extracts rich in ergosterol did not induce any adverse effects on the level of lymphocytes [Novaes *et al*., 2011].

Antimicrobial and antiviral activity of *Agaricus bisporus*

The ethanolic extract of fruiting bodies of *A. bisporus* contains various components with antimicrobial activity. The freeze-dried extract of this species displays activity towards *Escherichia coli* CBAB 2 (Minimum Inhibitory Concentration – MIC – 5 mg/mL), and also against *Staphylococcus aureus* ATCC 6588 (Gram negative). On the other hand, *Pseudomonas aeruginosa* ATCC 15442 has proved to be the most resistant strain, with a MIC value of 15 mg/mL [Vamanu, 2012].

The antimicrobial action of numerous mushroom species (including *A. bisporus*) is due to high contents of chitosan and chitin. Chitin and its deacetylated derivative – chitosan, are polysaccharides whose molecular weight is relatively high (similar to the ones found in crustaceans), which could suggest that their antibacterial properties are reduced. The antimicrobial effect of chitin and its derivatives increases with a decrease in the molecular weight. The activity is based on decreasing bacterial adhesion to the culture medium [Rajewska *et al.*, 2004]. Research into *Agaricus campestris*, a species closely related to *A. bisporus*, has shown the presence of agarodoxin – a benzoquinone derivate. This substance is an antibiotic and shows activity against *Staphylococcus aureus* (golden staph) [Muszyńska *et al*., 2011]. *A. bisporus*, on the other hand, shows activity against *Micrococcus luteus, Micrococcus flavus, Bacillus subtilis, Bacillus cereus, Candida albicans,* and *Candida tropicalis* [Öztürk *et al*., 2011].

CONCLUSION

The fruiting bodies of *Agaricus bisporus*, which is one of the most commonly cultivated and consumed mushrooms, are a good source of many substances with biological activity. Because of its ability to accumulate physiologically-active compounds, metals and vitamins, *A. bisporus* is not only a very popular delicacy but also an effective additive for the human diet. Due to high contents of bioelements and organic compounds essential for humans, its fruiting bodies consumption provides a high nutritional value. *A. bisporus* also contains substances that are well known for decreasing blood sugar levels and changing lipid profiles. Additionally, it has anti-carcinogenic, antioxidant, antibacterial, and antiviral properties. Determination of ergothioneine and tyrosinase in fruiting bodies has partially explained their activities and has made this species a significant mushroom with a medical and nutritional value.

Until today, numerous researches have been conducted in a model of the human digestive tract. These experiments showed that the fruiting bodies and biomass of *in vitro* cultures of *A. bisporus* release physiologically-active substances to artificial digestive juices. The next stage of research should be to determine the absorption level of the examined compounds which were previously released to artificial digestive juices. For this reason, our future research will address the precise determination of released substances and establishing the percent in which these physiologically-active compounds are absorbed by passive and active transport.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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