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REVIEW PAPER

Nutritional value and health-promoting properties of *Agaricus bisporus* (Lange) Imbach

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Summary

The white button mushroom *Agaricus bisporus* (Lange) Imbach is an edible mushroom of top economic significance. In recent years the consumption of fruiting bodies of this species has been increasing in Poland. The article characterises the chemical composition and health-promoting properties of white button mushrooms. The latest scientific research confirms that the fruiting bodies of white button mushroom have high nutritional value. They contain good quality proteins, necessary unsaturated fatty acids, fibre, some vitamins and numerous minerals. Apart from that, white button mushroom fruiting bodies contain a wide range of bioactive substances, which have a positive influence on health, such as polysaccharides, glycoproteins, tocopherols, polyphenols and other antioxidants, e.g. ergothioneine. Apart from the antioxidant properties, the white button mushroom also has anti-inflammatory, antimicrobial, antifungal, anticancer, immunomodulatory, hepatoprotective and anti-atherosclerotic activities.

Key words: ***button mushroom, cultivated mushrooms, nutrients, active substances, medicinal properties***

Słowa kluczowe: ***pieczarka dwuzarodnikowa, grzyby uprawne, składniki odżywcze, substancje aktywne, właściwości lecznicze***

INTRODUCTION

Various scientific centres all over the world conduct research on the influence of mushrooms on human health [1-3]. Many studies confirm the fact that mushrooms are added to dishes not only to give a specific taste and aroma, but they are also a valuable source of nutrients and health-promoting substances [4]. At present both cultivated and wild-growing mushrooms are classified as a special food also known as a functional food [5].

The fruiting bodies of different mushroom species contain a lot of active ingredients, such as: polysaccharides, triterpenoids, specific proteins, and phenolic compounds. Mushrooms have been documented to have a wide range of health-giving properties. They exhibit antineoplastic, immunostimulatory, antioxidant, antibacterial, antiviral and antidiabetic properties. They protect the heart, blood vessels and liver, and they reduce cholesterol in the blood [6-9]. The most important mushroom species with therapeutic properties are: *Ganoderma lucidum*, *Lentinula edodes*, *Grifola frondosa*, *Coriolus versicolor* and *Cordyceps sinensis* [10].

There is an increasing number of scientific reports which confirm the high dietary value and a wide range of health-giving properties of mushrooms of the *Agaricus* genus [11]. The fruiting bodies of the following species exhibit the widest spectrum of health-giving properties: *A. brasiliensis* (*A. blazei*) [12-14], *A. sylvaticus* [15, 16] and *A. bisporus* [17]. *A. bisporus*, known as the white button mushroom, is a good source of nutrients and many bioactive substances. The health benefits of the species result from the combination of its nutritional value, antioxidant properties and other therapeutic effects. Numerous health-promoting substances were isolated from fruiting bodies of this species as well as from its mycelium [18, 19].

A. bisporus is an edible mushroom which naturally occurs in fields, grasslands and meadows in Europe and North America. At present it is also the most commonly grown mushroom species around the world [20]. It is estimated that the annual consumption of mushrooms in Europe amounts to 2 kg *per capita* [21]. Mushroom production is an important branch of horticultural production. Poland is a leading mushroom producer and exporter in Europe. More than 300,000 tonnes of mushrooms are produced in Poland every year. In recent years the consumption of mushrooms has tended to increase in Poland. The propagation of health-promoting properties of mushrooms follows the current trend to use natural substances to prevent and treat numerous civilisation-related diseases.

THE NUTRITIONAL VALUE OF FRUITING BODIES

Basic composition

Amino acids and proteins

Mushroom fruiting bodies are a good source of protein. The content of protein in fresh mushrooms ranges from 1.23% to 3.08% [22]. The quality of the protein is determined by the content of exogenous and endogenous amino acids, the proportion of individual exogenous amino acids (their proportion should be similar to the proportion of body proteins), and the digestibility of protein products. The content of amino acids in the protein in *A. bisporus* is very well balanced. Like in other mushrooms, methionine and cysteine are the limiting amino acids. *A. bisporus* is characterised by low valine content, in comparison with the reference protein [23]. The content of other exogenous amino acids is much greater than the amounts in the FAO/WHO reference protein. *A. bisporus* is an excellent source of tryptophan, isoleucine and threonine. The content of these amino acids is respectively 200%, 82% and 74% greater than in the reference protein. There is a high content of exogenous amino acids in fresh, preserved and frozen mushrooms. As far as endogenous amino acids are concerned, fresh white button mushroom fruiting bodies contain the most glutamic acid, aspartic acid and arginine, i.e. 6.2, 8.1 and 8.0 g per 100 g of total protein [24, 25]. The content of individual free amino acids in *A. bisporus* fruiting bodies ranges from 0.8 to 14.1 $mg \cdot g^{-1}$ DM. The total content of free amino acids amounts to 44.2 $mg \cdot g^{-1}$ DM [26].

Carbohydrates

Carbohydrates are the most abundant nutrients in mushrooms. Fresh fruiting bodies contain about 6% of carbohydrates, whereas the average content of carbohydrates in dry fruiting bodies is 53%. Polysaccharides make a considerable part of carbohydrates in *A. bisporus*. They include glycogen, which is a reserve compound in mushrooms, and insoluble compounds, such as chitin and hemicelluloses.

such as glucose, mannose, galactose, ribose and fructose, which may make up to 30% of the total content of carbohydrates. *A. bisporus* also contains sucrose, lactose, raffinose, mannitol, maltose and trehalose. Fruiting bodies also contain inositol, glucuronic and galacturonic acids. The content of carbohydrates is considerably influenced by the storage time of mushrooms. The highest content of carbohydrates is found in fresh fruiting bodies. When mushrooms were stored at a temperature of 12°C for 12 days, the total content of carbohydrates decreased by 55%, whereas the content of fructose dropped as much as nine times [27].

Mushroom cell walls contain chitin, chitosan, hemicelluloses and α- and β-glucans (Fig. 1). They are a source of fibre, which is a valuable nutrient for human health [28, 29]. Edible macromycetes, including the white button mushroom *A. bisporus*, are rich in fibre. Mushroom fibre contains a wide range of compounds with different physical, chemical and physiological properties. Depending on solubility in water, we can distinguish insoluble fibre, e.g. cellulose, lignins, chitin, and soluble fibre, e.g. β-glucans and chitosans [30].

The content of fibre in mushrooms depends on the maturity of the fruiting bodies and the type of substrate. Dry mushrooms contain about 25% of fibre in the form of soluble and insoluble fractions. Augustin *et al.* [31] and Vetter [32] claim that mushroom cell walls contain large amounts of polysaccharides, such as chitin (up to 80% in dry mushrooms), cellulose, hemicelluloses, mannans and β- and α-glucans.

The content of chitin in fruiting bodies is characteristic of the species [33]. The average content of chitin in *A. bisporus* fruiting bodies is much larger than the content measured in species such as *Pleurotus ostreatus* and *L. edodes*. The content of chitin is similar in all *A. bisporus* strains [32]. The content of chitin in the *A. bisporus* cap and stem amounts to 6.68 and 7.25% DM, respectively.

Fatty acids and lipids

The fat content in mushroom fruiting bodies amounts to 0.14–0.90% [5, 22]. Fat is mostly found in the form of free fatty acids, mono-, di- and triglycerides and sterols. The identified sterols in *A. bisporus* are ergosta-7,22-dienol, ergosta-5,7-dienol, and ergosta-7-enol (fungisterol) [34]. Fat is mostly composed of unsaturated fatty acids (70%) and ergosterol (15%). The researchers identified 13 fatty acids [35]. The total amount of saturated fatty acids was 0.3%, palmitic acid being the most abundant (13.35%). The total content of unsaturated fatty acids amounted to 79.7%, linoleic acid being the most abundant. The content of polyunsaturated fatty acids significantly increases the dietary value of mushrooms, which can be recommended to people with high cholesterol levels in the blood.

Mineral compounds

Mushroom fruiting bodies provide considerable amounts of absorbable mineral ingredients [28, 36, 37]. *A. bisporus* fruiting bodies can be recommended to supplement the diet with all the minerals that are necessary for health [38]. Studies proved that there was higher content of most minerals in the cap than in the stem, except iron and calcium, which were more abundant in the stem [33]. Potassium and phosphorus are the most abundant elements in *A. bisporus* mushrooms. Their content amounts to 38,000–39,500 and 10,400–11,230 $mg \cdot kg^{-1}$ DM, respectively. There are smaller amounts of magnesium (1,110 $mg \cdot kg^{-1}$), calcium (870 $mg \cdot kg^{-1}$) and sodium (850 $mg \cdot kg^{-1}$). Mushrooms contain valuable microelements, i.e. zinc (60.5–62.4 $mg \cdot kg^{-1}$), iron (44.5–49.9 $mg \cdot kg^{-1}$) and copper (957.7–64.7 $mg \cdot kg^{-1}$). The content of selenium in white button mushroom fruiting bodies amounts to 2.80 $mg \cdot kg^{-1}$ and it is greater than in other mushroom species [39]. There were experiments in which mushrooms were grown on substrates enriched with selenium, zinc and copper. They showed that there was a high content of these elements in fruiting bodies, which can potentially be used as nutraceutics [40].

Vitamins

Mushroom fruiting bodies contain some vitamins, mostly B vitamins, vitamin D_2 and small amounts of vitamin A, E and C [15]. Fresh *A. bisporus* fruiting bodies are a good source of B vitamins. The content of vitamin B_1, B_2 and B_3 amounts to 6–10, 35–51 and 430 $mg \cdot kg^{-1}$ DM, respectively, whereas the content of vitamin B_6 is 954.7 $g \cdot 100g^{-1}$ DM. Mushrooms lose significant amounts of B vitamins in culinary processing, i.e. 36–51% of vitamin B_1, 36–62% of vitamin B_2 and 9–73% of vitamin B_3 [21]. *A. bisporus* fruiting bodies also contain vitamin C – 10.6 $mg \cdot 100g^{-1}$ DM and β-carotene – 1.154 $mg \cdot 100g^{-1}$ DM. As far as tocopherols are concerned, α-tocopherol is the most abundant compound (3.13 $mg \cdot 100g^{-1}$ DM). There is small content of β-tocopherol (0.04 $mg \cdot 100g^{-1}$ DM) [21]. Mushrooms contain considerable amounts of ergosterol – provitamin D_2. The content of ergosterol ranges from 61.5 to 186.1 mg·100g^{-1} DM, so it is a good source of provitamin D_2. Regular consumption of mushrooms may prevent a deficit of vitamin D [41]. Studies proved that the exposure of mushroom fruiting bodies to UV-B radiation after harvesting increased the content of vitamin D_2 but did not lower their quality. The irradiation of sliced mushrooms was more effective than the irradiation of whole fruiting bodies, because the area of exposure was bigger [42]. The exposure of mushroom fruiting bodies to ultraviolet radiation immediately before harvesting increased the content of vitamin D_2 proportionally to the dose of UV-B radiation [43].

Other bioactive compounds

Specific polysaccharides

Researchers are particularly interested in polysaccharides in mushrooms due to their antineoplastic properties. Glucans are the most important polysaccharides, as they play a significant role in the prevention and treatment of various diseases. The total content of glucans in the extract from *A. bisporus and A. brasiliensis* mushrooms is much greater than the amounts in the extracts from other mushrooms, such as *G. lucidum and Phellinus linteus* [44]. *β*-glucans are a more abundant fraction, as their content ranges from 22.8% to 58.2%. *β*-glucans in higher fungi may appear both in the soluble and insoluble fibre fraction [45].

β-glucans are long-chain multidimensional glucose polymers in which individual glucopyranose molecules are linked by *β*-glycosidic bonds. The anticancer activity of *β*-glucans chiefly applies to forms (1→3)/(1→6)-*β*. The antineoplastic properties of *β*-glucans in mushrooms result from strong intensification of the immune response rather than from their direct cytotoxic properties [46, 47]. *β*-glucans in mushrooms also exhibit antibacterial, antiviral and anti-allergic properties. These compounds reduce excessive cholesterol synthesis, blood pressure and glucose concentration in the blood [2]. They also prevent diabetes [48]. *β*-glucans in mushrooms have anti-oxidative properties [49, 17].

Gamma radiation caused significant changes in *β*-D-glucan in *A. bisporus* mushrooms [19]. The radiation reduced the molecular weight and changed some properties. The viscosity of *β*-D-glucan was reduced, but its solubility and anti-oxidative potential increased. The authors indicated that irradiated *β*-D-glucan had high health-promoting potential and it could be used as a component of functional food and pharmaceuticals.

Polyphenols and other compounds with antioxidant activity

Studies have proved the presence of numerous antioxidants in mushrooms [50]. Polyphenols are the main group, including flavonoids and phenolic acids. Apart from antioxidant activity, many other bioactive properties have been attributed to phenolic acids from mushrooms, especially antitumor and antimicrobial [51]. *A. bisporus* fruiting bodies contain the following phenolic acids: gallic acid, caffeic acid, ferulic acid, coumaric acid, protocatechuic acid, and cinnamic acid [52]. The total content of phenolic compounds in *A. bisporus* mushrooms expressed as a pyrocatechol equivalent amounts to 316–384 mg PEs·100 g^{-1} of fresh weight, whereas the content of flavonoids expressed as a quercetin equivalent amounts to 379–669 QEs·100 g^{-1} of fresh weight [35]. *A. bisporus* fruiting bodies also contain ergothioneine, a histidine derivative, which is one of the strongest antioxidants. The content of ergothioneine in *A. bisporus* fruiting bodies ranges from 1.2 to 1.8 mg·g^{-1}, whereas the content in the mycelium ranges from 0.5 to 1.1 mg·g^{-1} [53]. Apart from that, vitamin C and E as well as *β*-carotene and *β*-glucans also exhibit antioxidant properties.

Indole compounds

Indoles are a very important class of bioactive compounds due to the role of neurotransmitters or their precursors. They also exhibit anticancer, antioxidant, and anti-ageing properties and regulate the blood coagulation processes [54]. *A. bisporus* is a good source of non-hallucinogenic indole compounds [40, 55]. They were indentified both in fruiting bodies and the mycelium (*in vitro* cultures) [35]. The content of indoles such as L-tryptophan, 5-hydroxy-L-tryptophan, melatonin, serotonin, tryptamine and 5-methyl-tryptamine in *A. bisporus* was reported by [56]. Other indole compounds, i.e. indoleacetic acid and kynurenic acid, were also identified in the methanol extract of *A. bisporus* fruiting bodies [57]. Among indole compounds the highest content of kynurenic acid (6.21 mg/100g DW) and serotonin (5.21 mg/100g DW) was determined.

Lectins

Lectins are another group of bioactive substances in *A. bisporus* fruiting bodies. The role of lectins in mushrooms is more complicated than the role of these proteins in plants [58]. Lectins are storage proteins, which take part in numerous processes responsible for the growth, development and metabolism of mushrooms. They probably protect mushrooms from toxins in the environment. Lectins exhibit numerous health-promoting properties in the human organism. They affect the immune system as they accelerate the maturity of immune cells. They exhibit antineoplastic properties thanks to their antiproliferative activity, without direct cytotoxic effects [59]. Lectins prevent the proliferation of different cells, such as keratinocytes, which results in a therapeutic effect in psoriasis. Lectins from *A. bisporus* mushrooms aid wound healing. There are also scientific reports on the positive effect of mushroom lectins in eye diseases, such as retinal detachment and glaucoma, and in healing wounds after eye surgery [60]. Studies proved that *A. bisporus* lectins reduced the blood sugar level [61].

Chitin and lovastatin

Chitin is another health-promoting substance in mushrooms. In the human alimentary tract it is converted into chitosan, which forms insoluble complexes with bile acids. It reduces the absorption and deposition of fats in the liver and muscles [62]. The hypolipidemic effect is intensified by lovastatin, which can be found in *A. bisporus* fruiting bodies. The average content of this compound in white button mushrooms is 565 $mg \cdot kg^{-1}$ DM and it is greater than in other mushroom species [63]. Lovastatin inhibits LDL oxidation. It has positive effects on the coagulation system and fibrinolysis. Both compounds prevent cardiovascular diseases.

HEALTH-PROMOTING PROPERTIES

Antioxidant activity

Regular consumption of *A. bisporus* may protect the organism from free radicals due to the high anti-oxidative potential of these mushrooms, which results from the presence of phenolic compounds and ergothioneine. Mushroom strains differ in their content of phenolic compounds, ergothioneine and anti-oxidative potential. The highest content of flavonoids and ergothioneine was found in the fruiting bodies of brown strains [53]. Studies proved that the methanol extract and the extract from *A. bisporus* fruiting bodies obtained by means of ethyl acetate contained more phenolic compounds and flavonoids than hexane extracts [35]. Thermal processing of mushrooms before consumption reduces their anti-oxidative activity by 45–79% due to the loss of phenolic compounds, flavonoids, L-ascorbic acid and carotenoids. The loss was even bigger when mushrooms were blanched. Therefore, this procedure is not recommended [21].

Anticancer activity

The content and interaction of numerous bioactive compounds, such as polysaccharides, lectins and phenolic compounds, which are present in white button mushroom fruiting bodies, results in their antineoplastic properties. The anticancer effect of *A. bisporus* extract was confirmed in *in vitro* investigations on neoplastic cell lines and in research conducted on animals. *A. bisporus* extracts inhibited the proliferation of HL-60 leukaemic cells by inducing their apoptosis [64]. The boiled extract inhibited the proliferation more than the raw one. The study conducted on mice proved that the *A. bisporus* extract inhibited the growth of prostate cancer DU145 and PC3 cells [65]. Lectins isolated from white button mushrooms caused the sensitivity of lung cancer and colorectal carcinoma cells to chemotherapeutic drugs. They inhibited the proliferation of cancer cells and strengthened the mechanisms of cellular anti-oxidative defence [66]. Two polysaccharide fractions ABP-1 and ABP-2 extracted from *A. bisporus* mushroom influenced the development of cancer [67]. The investigations proved that both fractions stimulated the production of nitrogen oxide, interleukin-6 and tumour necrosis factor (TNF-α). Both ABP-1 and ABP-2 inhibited the growth of MCF-7 breast cancer cells, but they exhibited a much lesser effect on colorectal carcinoma, prostate cancer, gastric cancer and sarcoma 180 cell lines.

Antimicrobial activity

A. bisporus extracts were effective against gram-positive bacteria, such as *Micrococcus luteus,* *M. flavus, Bacillus subtilis* and *B. cereus* as well as fungi, such as *Candida albicans* and *C. tropicalis* [35]. The methanol *A. bisporus* extract exhibited antimicrobial activity against *Escherichia coli, Proteus, Pseudomonas aeruginosa* and *Staphylococcus aureus* bacteria and *Aspergillus niger* fungi [68]. *A. bisporus* extracts could be used as natural preservatives in yoghurts because they inhibited the development of the following microorganisms in dairy produce: *Staphylococcus aureus*, *Salmonella* spp., *Escherichia coli, Shigella* spp., *Listeria monocytogenes* and *Yersinia enterocolitica* [14]. *A. bisporus* aqueous enzymatic extracts exhibited also antiviral potential. They showed inhibitory activity against HCV protease so they could be used for prevention of HCV infection [69].

Anti-inflammatory activity

The study showed that fucogalactan, fucomannogalactan and mannogalactan isolated from *A. bisporus* var. *hortensis* exhibited anti-inflammatory and analgesic properties [70]. Heterogalactan exhibited the potential to fight sepsis in mice [71]. The effect may have been caused by the anti-inflammatory properties of this polysaccharide. Sepsis is a very serious medical problem and it is the main cause of death in intensive care units. It consists in overproduction of pro-inflammatory mediators, which appear due to bacterial infections. The study on mice showed that fucogalactan isolated from *A. bisporus* fruiting bodies exhibited anti-inflammatory properties. The research proved that it had a strong inflammatory effect and could be used to fight sepsis [18]. Medicinal activities of *A. bisporus* are summarised in table 1.

A. bisporus, the species which is commonly grown and consumed in Poland and all over the world, is characterised by its high nutritional value and content of numerous bioactive substances. The consumption of these mushrooms provides valuable amino acids, unsaturated fatty acids, fibre, minerals, B vitamins and vitamin D. The fruiting bodies are a good source of antioxidants, which protect the organism from free radicals. Addition of *A. bisporus* fruiting bodies to different dishes enriches the taste of the food and provides many health-promoting components.

Ethical approval: The conducted research is not related to either human or animal use.

Conflict of interest: Authors declare no conflict of interest.

Table 1.
Medicinal activities of *Agaricus bisporus* fruiting bodies

Properties	Bioactive compounds	References
Antioxidant	polyphenols flavonoids	[21]
	vitamin C tocopherols	[35]
	ergothioneine	[19]
	β-glucans	[17]
Anti-inflammatory	heterogalactan	[71]
	fucogalactan	[18]
Antibacterial	β-glucans	[68]
		[35]
		[14]
Anticancer	polysaccharides	[71]
	lectins	[58]
	phenol compounds ergosterol	[72]
Immunomodulatory	polysaccharides	[18]
Anticholesterolemic	lovastatin chitin	[62]
Antidiabetic	β-glucans	[48]
		[61]
Neuroprotective	indole compounds	[55]

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