

Nutritional and Functional Properties of Edible Mushrooms: A Food with Promising Health Claims

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Abstract: Over the past two decades, there has been a steady flow of publications about the health effects related to mushrooms consumption. They represent a valuable source of protein, present high levels of fiber, some vitamins and minerals, and they also have reduced amount of fat and sodium. In addition, their complex carbohydrates profile can strengthen considerably the immune system.

Edible mushrooms have been related to significant functional properties due to their bioactive compounds, such as eritadenine, phenolic compounds, sterols (as ergosterol), chitosan, etc., These substances are considered as important agents in the prevention and treatment of different health conditions like obesity, diabetes, or cardiovascular disease. However, it is important to remember that most of scientific studies are made in animal models and, therefore, some evidences regarding mushroom consumption have yet to be confirmed in clinical trials.

Despite of the growing appeal for humans by their medicinal effects and nutritional value, mushrooms are also very appreciated for their texture, flavor, and versatility in culinary. They can be easily incorporated into any kind of dish, improving the dietary diversity without adding many calories.

The information presented in this review point out that the positive effect of mushrooms on health is beyond basic nutrition. Therefore, it is very valuable expanding our knowledge about mushrooms, in order to identify all their active principles and the mechanisms involved in each health benefit, getting aware about the doses required to achieve that, in a safe range for humans.

Keywords: Mushroom, functional food, disease prevention, antioxidant, umami.

INTRODUCTION

There is a growing interest in the relationship between diet and health in the last two decades. The traditional concept of "adequate nutrition" or "adequate supply of nutrients" to meet the basic body needs is currently being replaced by concepts such as "optimal nutrition", "health promotion", or even "disease prevention" [1]. Therefore, the need to study the role of certain foods that contain nutrients or bioactive compounds with biological activity to modulate the development of specific pathophysiological processes, becomes very important. In fact, different studies have revealed that many chronic diseases, such as cardiovascular disease (CVD), Diabetes Mellitus (DM), autoimmune diseases, cancer, obesity, and neurological diseases, could be influenced by the type of fat or level of antioxidants presented in the diet. Additionally, epidemiological studies have demonstrated an inverse relationship between fruits and vegetables consumption and the occurrence of

those chronic diseases, since these groups of foods are high in different bioactive compounds with antioxidant activity, as the vitamin E, vitamin C, carotenoids, and also phenolic compounds [2]. In this way, many nutraceutical properties have been linked to mushrooms, such as anti-cancer, anti-tumor, cholesterol lowering, antiviral, antibacterial, or immunomodulatory [3].

Mushrooms are defined as macrofungi and may grow above or below ground [4]. They are the visible reproductive (fruiting body) structures of some types of fungi, which release tiny spores that are easily carried on air currents to new sites. When spores reach a favorable place to grow, they germinate and send out long, thin filaments, usually colourless, called hyphae. The body of most fungi is made up of a vast number of hyphae, all intertwining to make up a tangled web called mycelium. When the mycelium has developed sufficiently, fruiting bodies such as mushrooms can be produced [5].

The edible class of mushrooms that shows potential medicinal and functional properties includes *Lentinus*, *Bisporus*, *Auricularia*, *Hericium*, *Grifola*, *Flammulina*,

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Pleurotus and *Tremella*. Other species are known only for their medicinal properties, since they are coarse, harder in texture, and are bitter in taste. These species include *Ganoderma*, *Trametes*, etc. [6]. It is unknown how many mushroom species exist, although some experts estimate that they number in the tens of thousands. It has been claimed that more than 10% of mushroom species are edible, and a roughly equal proportion of them is considered to be poisonous [7]. Some of the most popular cultivated mushrooms in the world are the button mushroom (*Agaricus bisporus*) and shiitake (*Lentinus edodes*). The first one is popular in the Western Europe and North America, while shiitake is ordinarily consumed in the Far East [8], and its popularity has also increased in the West. Since ancient times, mushrooms have been consumed by humans, not only as a part of the usual diet, but also as a delicacy. Some species are greatly appreciated for an extremely high value in gourmet cooking [5].

Because of their attractive taste, aroma and nutritional values, edible mushrooms are valuable components in the diet. It is important to highlight their high protein, fiber, vitamin and mineral contents, and also a low-fat and sodium levels, that make these mushrooms very attractive ingredients for a healthy diet [3, 5]. In addition, the different bioactive compounds found in the edible mushrooms can have important implications in the prevention and treatment of various diseases [5, 7, 9]. For this reason, it has also been considered as a functional food in some countries [10].

The aim of this review was to feature the nutritional and palatable properties of edible mushrooms, as well as their therapeutic aspects and health benefits when consumed as part of the usual diet.

METHODS

We synthesized the existing information in the literature available in Medline, AMED, EMBASE and Medline from Pubmed; by using the search terms "mushroom", "functional food", "disease prevention" and "antioxidant, umami".

NUTRITIONAL COMPOSITION

Since the nutritional composition may vary in different edible mushroom, we will present the general characteristics of the most commonly consumed varieties. Mushrooms are low in calories, may contain only 22 kcal per 100 grams. The nutritional composition of some of the most popular edible mushrooms around the world, are presented in Table 1.

Dry matter in mushrooms is usually between 8 and 12%, though values as high as 13.7% has been reported. The dry matter content is influenced by irrigation, type of compost and strain, but it may also vary within and between flushes [11]. The high water content in fresh commercialized mushrooms limits the nutritional value and its lifetime under suitable conditions [10].

Protein level is moderated high in mushrooms (19-35%). Normally, it is lower than that present in most animal meats, but it is higher in most of the vegetables, fruits and other foods. In *A. bisporus*, protein level usually ranges from 22.7 to 40.8 g/100g of dry weight. Mushrooms also present an important content of essential amino acids [8], although it can vary widely among species (for example, between 32 - 43% of the total amino acid contents in *A. bisporus*). Mushrooms are considered rich in glutamic acid, aspartic acid and arginine, but deficient in methionine and cysteine. Nevertheless, the amino acid composition of their proteins is comparable to animal protein, which is of particular importance when there is an indication for a dietary restriction in animal-based foods [12].

Edible mushrooms provide low amounts of total fat (range from 1.3 to 5.8% of the dry matter). In general, unsaturated fatty acids are predominant over saturated fatty acids, especially palmitic acid (C16:0), oleic acid (C18:1) and linoleic acid (C18:2). *A. bisporus* lipid profile also includes the neutral lipids, such as free fatty acids, glycerides, sterols, and phospholipids.

Carbohydrates are the main component of mushrooms, after moisture. This nutrient ranges from 35 to 70%, and presents some heterogeneity among species. *A. bisporus* contains between 43.3 and 61.3 g of carbohydrates per 100g of dry weight.

The carbohydrates include polysaccharides (such as glucans, hemicelluloses, pectin, glycogen like polysaccharide and chitin), monosaccharides (such as ribose, fructose, glucose and mannose), disaccharides (such as trehalose and sucrose), sugar alcohols (such as mannitol and inositol) and sugar acids (such as galacturonic and gluconic acids). Most of the carbohydrates presented in mushrooms are structural polysaccharides of the cell walls, and they cannot be digested by humans digestive enzymes. According to its morphological stages, the dietary fiber content and composition of edible mushrooms may vary widely among them. Normally, it can be observed an appreciable level of total fiber, ranging from 5.5 to 42.6 of dry weight in *Boletus* group, *Agrocybe aegerita*, *A.*

Table 1: Nutrition Facts of some of the Most Popular Edible Mushrooms Around the World (Adapted from USDA, 2013) [62]*

Nutrients (Per 100g)	Scientific name / Common name	<i>Cantharellus cibarius</i> / Chanterelle mushroom (raw)	<i>Agaricus bisporus</i> / White mushroom (raw)	<i>Agaricus bisporus</i> / Portabello mushroom (raw)	<i>Lentinus edodes</i> / Shiitake mushroom (raw)	<i>Flammulina velutipes</i> / Enoki mushroom (raw)	<i>Grifola frondosa</i> / Maitake mushroom (raw)	<i>Pleurotus ostreatus</i> / Oyster mushroom (raw)
	Water (g)		89.85	92.45	92.82	89.74	88.34	90.37
Calories (kcal)		38	22	22	34	37	31	33
Total fat (g)		0.53	0.34	0.35	0.49	0.29	0.19	0.41
Saturated fatty acid (g)		n/a	0.050	0.060	n/a	0.020	0.030	0.062
Monounsaturated fatty acid (g)		n/a	0.0	0.020	n/a	0.0	0.030	0.031
Polyunsaturated fatty acid (g)		n/a	0.160	0.117	n/a	0.090	0.090	0.123
Total Carbohydrate (g)		6.86	3.26	3.87	6.79	7.81	6.97	6.09
Dietary fiber (g)		3.8	1.0	1.3	2.5	2.7	2.7	2.3
Sugar (g)		1.16	1.98	2.5	2.38	0.22	2.07	1.11
Protein (g)		1.49	3.09	2.11	2.24	2.66	1.94	3.31
Glutamic acid (g)		n/a	0.343	0.319	0.680	0.380	0.264	0.632
Calcium (mg)		15	3	3	2	0	1	3
Iron (mg)		3.47	0.5	0.31	0.41	0.087	0.3	1.33
Magnesium (mg)		13	9	n/a	20	16	10	18
Phosphorus (mg)		57	86	108	112	105	74	120
Potassium (mg)		506	318	364	304	359	204	420
Sodium (mg)		9	5	9	9	3	1	18
Zinc (mg)		0.71	0.52	0.53	1.03	0.65	0.75	0.77
Selenium (ug)		2.2	9.3	18.6	5.7	2.2	2.2	2.6
Thiamin (mg)		0.015	0.081	0.059	0.015	0.225	0.146	0.125
Riboflavin (mg)		0.215	0.402	0.130	0.217	0.2	0.242	0.349
Niacin (mg)		4.085	3.607	4.494	3.877	7.032	6.585	4.956
Vitamin B6 (mg)		0.044	0.104	0.148	0.293	0.100	0.056	0.11
Vitamin B12 (ug)		n/a	0.04	0.05	n/a	0.0	0.0	0.0
Vitamin D (D2+D3) (ug)		5.3	0.2	0.3	0.4	0.1	28.1	0.7
Vitamin D2 ^a (ug)		5.3	0.2	0.3	0.4	0.1	28.1	0.7
Vitamin D3 ^b (ug)		0.0	0.0	0.0	0.0	0.0	0.0	0.0

*Nutrient values and weights are for edible portion.

n/a: information is not available.

a: Ergocalciferol.

b: Cholecalciferol.

bisporus, *Pleurotus eryngii* and *Ostreatus*. Mushrooms present higher levels of insoluble dietary fiber (2.28 – 8.99g/100g fresh weight) than soluble fiber (0.32–2.20 g/100 g edible weight). Some compounds that claimed to have beneficial and functional properties are present in the dietary fiber fraction. One of these is the chitin, as presented later in this review.

Mushrooms also have been reported to contain 0.17% DNA and 2.49% RNA, and 0.11% 5'-nucleotides [13]. Some of these compounds are important for the

flavor and palatability of mushrooms, as it will be later commented.

Regarding vitamins, mushrooms can be considered a good source of vitamin B2, vitamin B3 and folates. Some species also present traces of vitamin C, vitamin B1, vitamin D, β -carotene (precursor of vitamin A), vitamin E and vitamin B12.

When compared with vegetables, mushrooms show a reasonable content of many mineral elements (6 –

10.5%). The main constituents found in the ash are potassium and, depending on the mushroom specie, phosphorus or magnesium, calcium, copper, iron and zinc [5].

The content of selenium in mushrooms is usually appreciable, ranging from 0.46 to 5.63 mg / kg of dry matter. It is a mineral trace element which acts as a cofactor in many enzyme systems and presents a strong anti-oxidative effect [14].

It is important to remember that the method of cultivation and the type of compost used, may affect the concentrations of mineral and trace element in mushrooms. Moreover, an accumulation of trace heavy metals can be detected in them, particularly toxic elements such as cadmium, lead and mercury, because such substances are commonly present in the culture substrates. However, some studies show that washing and peeling the mushrooms may reduce the heavy metal content in the consumable parts.

BIOACTIVE COMPOUNDS

Bioactive compounds are essential and non-essential substances (e.g., vitamins or polyphenols) present as natural constituents in food. They provide health benefits beyond the basic nutritional value of the product that occur in nature. These compounds can also be referred to as nutraceuticals, a term that reflects their existence in the human diet and their biological activity [15].

In addition to the nutritional components, some edible mushrooms are rich in bioactive compounds. The contents of such compounds may vary considerably in edible mushrooms, since the concentration of these substances is affected by differences in the strains, substrate, cultivation and fruiting conditions, developmental stage, age of the fresh mushrooms, storage conditions, as well as processing and cooking practices.

The bioactive compounds in mushrooms may play important role in prevention and treatment of different illness, due to the effect observed on oxidation [5, 10, 16, 17], lipid profile [5, 18], glucemic index [18, 19], and satiety [20].

The most important bioactive compounds present in the mushrooms, are presented next:

β -Glucans

They are polysaccharides of D-glucose monomers linked by -glycosidic bonds. It may represent from 4 to

13% of the total dietary fiber, considering that dietary fiber fractions may vary depending on mushrooms species. Some polysaccharides that belong to the β -glucan family, could inhibit tumor growth by stimulating the immune system. Specifics β -glucans are recognized by pattern-recognition receptors on immune cells such as monocytes, granulocytes and dendritic cells. In mushrooms, they are also known to exert immunomodulatory effects *via* activation of macrophages, balance of T helper cell populations and subsequent effects on natural killer (NK), and also *via* cytokine production. Besides the function they may play on the immune system, β -glucans are also associated with anticoagulant functions, as well as reductions of cholesterol [5] and glucose levels and glucose levels [21], Chen and Raymond (2008) [22] suggest that beta-glucans are potentially beneficial in the treatment of diabetes and associated cardiovascular risks, despite the mechanisms behind this effect still need to be further clarified.

Chitin

Chitin is a structural polymer of the fungal cell wall and takes part of the insoluble fiber fraction. It is a nitrogen-containing polysaccharide that consists of monomers of N-acetyl-glucosamine.

In many strains, the chitin fraction will increase as mushrooms grow and mature. Around 30% of the total dietary fiber occurs as chitin, and may be detected in the form of glucosamine.

The high fat diet-induced obese mice, supplied with a chitosan (the most important derivative of chitin) supplement (5%) from *A. bisporus* during ten weeks, showed lower lipid absorption and serum adipocytokine levels [23]. Consequently, the use of such supplement could contribute to reduce fat deposition in the liver (a decrease of triglyceride content by 39%) and muscle (a decrease of triglyceride content by 66%), besides lowering the fat mass.

Ergothioneine

Mushrooms were discovered recently to be the primary source of ergothioneine ET (2-thiol-L-histidine-betaine or 3-(2-sulfanyldiene-1,3-dihydroimidazol-4-yl)-2-trimethylazaniumyl) propanoate), in a concentrations ranging from 0.4 to 2.0 mg/g of dry weight [16]. ET is a naturally occurring thiol containing amino acid. It is water soluble and it could exerts antioxidant properties through multiple mechanisms, one of which would represent a powerful ability of ET to

scavenge free radicals [24-26]. The physiological role of ET has yet to be established. Numerous *in vitro* assays have demonstrated the antioxidant and cytoprotective capabilities of ET against a wide range of cellular stressors, but the antioxidant role still needs to be fully verified *in vivo* [16, 27].

Polyketides

They are structurally complex organic compounds exhibiting many biological and pharmacological activities such as antibacterial, antifungal, anticholesterol, antiparasitic, anticancer, and immunosuppressive properties.

Statins, considered fungal secondary metabolites, are used for the treatment of dyslipidemia and the prevention of cardiovascular disease due to powerful inhibitory effect on 3-hydroxy-3-methyl-glutaryl coenzyme A reductase (HMG-CoA reductase), the first enzyme in cholesterol biosynthesis that catalyzes the conversion of HMG-CoA to mevalonate (an early and rate limiting step in cholesterol biosynthesis)

This inhibitory activity was initially attributed to fungal polyketides such as statins [28]. However, a controversial on the natural occurrence of statins in fungi have arisen. Thus, recently it has been reported high HMGCR inhibitory activity in edible mushrooms, but not detectable statin levels were found [29, 30].

Ergosterol, the Provitamin of Ergocalciferol (Vitamin D₂)

An adequate source of dietary vitamin D is especially important for healthy and active persons during the winter, especially in northern latitude, since this vitamin is not only obtained from the diet, but also through cutaneous synthesis in the presence of ultraviolet light supplied by sunlight or other ultraviolet B light sources. Vitamin D₃ (cholecalciferol) is present in animal sources and is the main form of vitamin D in food. Vitamin D₂ (ergocalciferol), which is usually of plant origin, is of minor importance because it is not abundant in foodstuffs [31]. However, Vitamin D₂ contents are relatively high in many wild mushroom species, as observed in *Chantarellus tubaeformis*, which contain vitamin D₂ at a concentration of 29.8 µg/100g fresh weight. Based on the recommended daily intake for adults (5 µg/day), the consumption of 100 g of such mushrooms could provide nearly one week of vitamin D requirement. *C. cibarius* was also found to contain high concentrations of vitamin D₂ (12.8 µg/100g), whereas other wild mushrooms evaluated can range from 2.9 to 5.8 µg/100g. Regarding to

cultivated mushrooms, only trace amounts of vitamin D₂ were found in the most popular type, *A. bisporus* [13]. On the other hand, reasonably high contents have been found in cultivated shiitake (22–1.10 µg/g dry matter) [7].

Mushrooms cultivated indoors contain lower levels of vitamin D₂ than those cultivated outdoors because the metabolic route from ergosterol to ergocalciferol (vitamin D₂) requires sunlight or artificial ultraviolet light. Common cultivated mushrooms could be remarkably enriched with vitamin D₂ by ultraviolet-B irradiation after harvest. It is worth noting that this is an easy way to improve the nutritional vitamin D value of common mushrooms and make them a better source of this nutrient [9], which could be very important for those institutionalized people that don't get sunshine for long periods [31], or even for those individuals with a limited intake of cholecalciferol from foods of animal origin, e.g. for vegans and vegetarians [9, 31]. It is important to remember that mushrooms are the only non-animal food source of vitamin D, and thus they are the only natural dietary source for vegans or vegetarians [13].

Phenolic Compounds

Among the antioxidant compounds, polyphenols have gained importance due to their large array of biological actions that include free radical scavenging, metal chelation enzyme modulation activities and inhibition of LDL oxidation. The term polyphenol refers to a complex group of compounds that comprises simple phenols such as phenolic acids and derivatives [32]. According to the literature, some common edible mushrooms have currently been found to possess antioxidant activity, which is well correlated with their total phenolic content [33], although other nutrients, as selenium, can also be considerably associated with a strong anti-oxidative effect [14, 34].

Nevertheless, other properties linked to phenolics have also increased the interest in the consumption of mushrooms, such as anti-inflammatory or antitumour activities [35].

The most important phenolic compounds found in different edible mushrooms are presented in Table 2.

EFFECTS OF EDIBLE MUSHROOMS: METABOLIC AND HEALTH BENEFITS

Immune Function

Numerous studies have described the effects of mushrooms and mushroom extracts on enhancing the

Table 2: Phenolic Compounds* Found in Five Edible Mushrooms (Adapted from Palacios et al., 2011) [32]

Mushroom specie	Phenolic compounds detected
<i>A. bisporus</i>	Caffeic acid, Catechin, Chlorogenic acid, p-Coumaric acid, Ferulic acid, Gallic acid, p-Hydroxybenzoic acid, <u>Homogentisic acid</u> , Protocatechuic acid, <u>Pyrogallol</u>
<i>B. edulis</i>	Caffeic acid, Chlorogenic acid, p-Coumaric acid, <u>Gallic acid</u> , Gentisic acid, <u>p-Hydroxybenzoic acid</u> , Homogentisic acid, <u>Protocatechuic acid</u>
<i>C. cibarius</i>	Caffeic acid, <u>Catechin</u> , Ferulic acid, Gallic acid, Gentisic acid, p-Hydroxybenzoic acid, Homogentisic acid, Protocatechuic acid, Pyrogallol
<i>P. ostreatus</i>	p-Coumaric acid, <u>Ferulic acid</u> , <u>Gallic acid</u> , <u>Gentisic acid</u> , p-Hydroxybenzoic acid, Homogentisic acid, Protocatechuic acid
<i>L. deliciosus</i>	Caffeic acid, Chlorogenic acid, Ferulic acid, Gallic acid, Gentisic acid, <u>p-Hydroxybenzoic acid</u> , Homogentisic acid, Protocatechuic acid, Pyrogallol

*The phenolic compounds detected in levels considerably higher when compared with other mushroom species presented in this table.

immune function. Some of the more effective compounds reported are β -glucans, polysaccharide naturally present in fungi. They can modulate immune defense by activating complement system, enhancing macrophages and NK cell function. The induction of cellular responses by mushroom and other beta-glucans is likely to involve their specific interaction with several cell surface receptors, such as complement receptor 3 (CR3; CD11b/CD18), lactosylceramide, selected scavenger receptors, and dectin-1 (betaGR) [36, 37]. As immunostimulating agent, which acts through the activation of macrophages, NK cell and also *via* T cells and their cytokine production, beta-glucan can also inhibit tumor growth. Furthermore, mushroom proteins, terpenes and furans have also been implicated in immune function [7, 9].

Anticancer

Polysaccharides extracted from a variety of mushrooms have been associated with antitumor effects, primarily in human cell lines. They usually belong to the beta-glucan family of compounds and appear to exert their anti-tumorigenic effects *via* enhancement of cellular immunity. In fact, based on *in vitro* studies, beta-glucans act on several immune receptors and trigger a group of immune cells, including macrophages, neutrophils, monocytes, NK cells and dendritic cells [38]. According to Akramiene et al. (2007) [37], by activating NK cell function, beta-glucans could interfere with angiogenesis and thus, inhibit the promotion and progression of the tumors.

In many mushrooms, proteoglycan is the fraction linked to the antitumor effects. According to Ji et al. (2011) [39], proteoglycan activates the immune system by modulating cytokine production.

Moreover, there are some information in the literature about specific beta-glucans as adjuvants to

cancer chemotherapy and radiotherapy. They could demonstrate a positive role in the restoration of hematopoiesis following by bone marrow injury [37].

The antitumor effect of mushrooms has been studied in breast, colorectal/colon, cervical, ovarian, gastric, prostate and pancreatic cancer. While studies in human cell lines provide supporting evidence, carefully and well-designed human clinical trials would be required before anti-cancer health outcomes in humans can be affirmed and validated.

Obesity

Obesity causes many complications, including dyslipidemia, diabetes, hypertension, and heart disease. Recently, obesity has also been associated with the increased incidence of many cancers [40]. Mushrooms contain few calories and fat. More than one third of the carbohydrates consists of fiber. Such characteristics and the high palatability make them a good food for weight management diet. According to Cheskin et al. (2008) [20], substituting ground white button mushrooms for lean ground beef in a single meal for four consecutive days could significantly reduce daily energy and fat intake, while maintaining ratings of palatability, appetite, satiation and satiety in a group of 64 subjects. In the author's opinion, substituting one food for another (low energy density foods for high energy density foods) within familiar recipes, may be more appealing to many prospective dieters than making dramatic or restrictive changes in dietary behavior.

Recent data in the literature have been suggesting that mushrooms could be considered a suitable natural way for preventing or even treating obesity. However, most of scientific studies are made in animal models and so, the evidences have yet to be confirmed in clinical trials.

Cardiovascular Disease

Studies have shown the effect of mushrooms consumption on some metabolic markers as total cholesterol, LDL and HDL cholesterol, fasting triacylglycerol, homocystein, blood pressure, oxidative and inflammatory damage; which potentially may reduce the risk of suffering cardiovascular diseases.

The intake of edible mushroom may reduce the cardiovascular risk due to the occurrence of specific substances and other bioactive compounds as dietary fiber [5]. The formation of viscous gels from soluble dietary fiber contributes to inhibit the cholesterol and triglycerol absorption and are related to an increase on the fecal excretion of bile acids and short-chain fatty acids (propionate), which inhibits acetate incorporation (substrate for sterols and fatty acid synthesis) to serum lipids.

Another important factor in the prevention of cardiovascular disease is the higher levels of unsaturated over saturated fatty acids, which ratio usually ranges between 3:1 - 4:1 [33]. Such profile may also be important for preventing atherosclerosis process [41] that has been considered as the most important factor associated with cardiovascular disease development [5].

Moreover, some polysaccharides present in mushrooms may promote cardiovascular protection. β -glucans exhibit hypocholesterolemic and anticoagulant functions [42, 43], while chitosan present the capacity to modify lipid metabolism [23].

In *L. edodes* and *A. bisporus* there is an adenosine analogue alkaloid or purine alkaloid called eritadenine, lentinacin or lentysine, which is associated to hypocholesterolemic effects [5, 44]. The main hypocholesterolemic action of eritadenine seems to be related to a modification of the hepatic phospholipid metabolism by inducing a phosphatylethanolamine N-methyltransferase (PEMT) deficiency, a liver-specific enzyme that is involved in the S-adenosylhomocysteine (AdoHcy) synthesis. AdoHcy is the precursor of homocysteine (Hcy) that is released into the circulation, and which is an independent risk factor for atherosclerosis. Zhao *et al.* (2009) [45] reported that PEMT reduction in mice may decrease atherogenic plasma lipoproteins, including triglycerides and Hcy levels.

Also, the dietary eritadenine can alter the fatty acid and molecular profile of liver and plasma. Regarding

fatty acid profile, eritadenine suppress the metabolic conversion of linoleic acid into arachidonic acid (AA) by decreasing the $\Delta 6$ -desaturase activity [44]. Considering that AA is the substrate for the production of a wide variety of eicosanoids (20-carbon AA metabolites), some of which are proinflammatory, vasoconstrictive, and/or proaggregatory, such as prostaglandin E₂, thromboxane A₂, and leukotriene B₄ [46], dietary eritadenine could be considered an important element of protection to the risk of cardiovascular disease.

Polyketide, as lovastatine, is other compound that has been found in mushrooms that can decrease intracellular cholesterol biosynthesis through inhibition of HMG-CoA reductase [17].

The content of potassium in mushrooms is also worthy of attention due to the high sodium intake in current diet of most of the people. The low concentration of sodium and the presence of a great amount of potassium in mushrooms (range observed in the *Pleurotus*

Species: 182–395 mg/100 g) could support an antihypertensive diet, which may help to keep the blood pressure in a suitable range for a cardiovascular protection [47].

Finally, the consumption of compounds that can act as antioxidants, as polysaccharides, ergothioneine, ergosterol, nicotinic acid, triterpenes (also important due to anti-inflammatory properties), phenolic compounds, or even nutrients as selenium, could also play an important role in the prevention of cardiovascular diseases.

Diabetes

A large number of animal studies, using both normal and diabetic animals, have demonstrated a hypoglycemic effect of mushrooms and mushroom components. This effect appears to be mediated through mushroom polysaccharides (possibly both alpha- and beta-glucans) *via* a direct interaction with insulin receptors on target tissues, although this mechanism remains to be confirmed. A randomized, double-blinded, and placebo-controlled clinical trial showed that *A. blazei* Murill (mushroom native to Brazil and widely cultivated in Japan for its medicinal uses) [19, 48] supplementation in combination with metformin and gliclazide, improved insulin resistance in subjects diagnosed with diabetes. An increase in adiponectin concentration after *A. blazei* Murill extract consumption for 12 weeks may be the mechanism that resulted in

the reported effect [19]. Clinical investigation in diabetic patients has also shown that Oyster mushroom consumption significantly reduced systolic and diastolic blood pressure, lowered plasma glucose, total cholesterol and triglycerides significantly, with no significant change in body weight, and no deleterious effects on liver or kidney function [18].

PALATABILITY PROPERTIES

Palatability is the word used to describe how well someone likes the flavor, aroma and texture of a food. All five senses are involved in determining food palatability, with taste playing a major role. However, the smell is also particularly important, as well as the shape and texture of the food [49].

Hundreds of odorous compounds have been identified in mushrooms, being classified as derivatives of octanes and octenes, lower isoprenoids, aldehydes and ketones, sulfurous (e.g. lenthionine) or heterocyclic compounds, and others. They also contain non-volatile and natural components, which bring out a rich and savory flavor known as umami taste [50], but also called as the fifth taste. It has characteristic qualities that differentiate it from other tastes, including a prolonged aftertaste.

Umami taste comes primarily from glutamate or glutamic acid, the most common non-essential amino acid. When glutamate is not bound to other amino acids as part of a protein chain, it gives the umami taste. However, when glutamate is combined with the ribonucleotides inosinate and guanylate (two ribonucleotides that contribute most to the umami taste), the impact of umami taste is further enhanced, which is commonly observed in seafood, meats and mushrooms.

The glutamate content in mushrooms varies by their specie, but most of them contain significant amounts of this amino acid. Shiitake mushroom is the variety with the highest content of glutamate [51]. It is interesting to notice that only animal products such as sardines, mackerel, tuna, pork, beef, and chicken contain inosinate. Nevertheless, mushrooms are the food with the highest guanylate levels [52].

Mushrooms are versatile foods. Due to their natural and savory flavors, they can be easily incorporated into a variety of dishes, providing diversity without adding many calories. Umami plays an important role in food acceptability and, according to Cheskin *et al.* (2008) [20], rates of palatability across the meat and mushrooms are very similar.

The time elected for the harvest could also be of importance for mushrooms palatability [53]. The egg stage (before the complete development of mushrooms pileus), seems to be the period for greater palatability, at least for *Pleurotus tuber-regium* and *Pleurotus P. sajor-caju*. In this sense, it would be better to harvest them at their early stages.

Although mushrooms do not belong to the vegetable kingdom, observations about the harvest period is very interesting to ponder, since the literature shows that the ripening of vegetables generally makes them more flavorful due to increase in their natural contents, as free amino acids (e.g., glutamate) [49].

MUSHROOMS AS FUNCTIONAL FOOD

The importance of functional foodstuffs on the world food market is increasing systematically.

According to the concept proposed by American and European experts, functional food should be an element of an appropriate diet, consumed on a regular basis and in normal amounts; while at the same time it should reduce the risk of specific diseases or exhibit an additional benefit to the health, apart from its basic nutritive value. In addition, a functional food should be characterized by an enhanced availability of the active substance naturally contained in it [54].

Based on the previous statement, edible mushrooms can be considered a functional food due their remarkable nutritional profile, bioactive compounds content and therapeutic properties described by several researchers. However, the health benefits just can be achieved if mushrooms take part of daily eating habits.

Nowadays, health-conscious consumers are increasingly looking for alternative ways that help control their own health and well-being. In this sense, following the idea about eating a balanced diet, including certain foods containing active compounds to reach health benefits and prevent from diseases like diabetes, hypertension, atherosclerosis, cancer, etc., have contributed to encourage many people to include mushrooms in their diet as a natural functional food [10]. It is important to highlight that just few direct intervention trials of mushroom consumption in humans have been performed to date, but all of them indicate that mushrooms are generally well accepted and tolerated [9].

In many different countries around the world, especially in Japan, edible mushrooms have been used

as a bioactive ingredient of some prebiotics and probiotics foods, or even in those foodstuffs targeted to regulate cholesterol, blood pressure, and lipid metabolism. Some food manufacturers in Japan are also using processed mushrooms as an additive in food production, in order to enhance flavor and protect the final product from oxidation. Moreover, the use of these additives is expected to promote health benefits, by improving fiber content and also the vitamin and mineral profile [55].

TOXICITY AND SAFETY

There have been relatively few direct intervention trials of mushroom consumption in humans, although those that have been completed to date indicate that mushrooms and their extracts are generally well-tolerated with few, if any, side-effects [9].

According to Clarke and Crews (2014) [56], poisonous fungi are often eaten by individuals and families as a result of misidentification. Larger poisoning events still occur across the world and are often the basis for identification of new mushroom toxins.

Consumption of poisonous mushrooms can cause various types of reactions, such as allergic gastroenteritis, psychological relaxation and fatal liver intoxication. The adverse effects range Depending on the type of mushroom, Toxicity may also vary in accordance with the amount and age of the mushroom, the season, the geographic location and the way in which the mushroom was prepared prior to ingestion. Cooking method of wild mushrooms seems to be relatively safe, but raw mushroom ingestion can be very dangerous [57].

The overall diversity of edible mushrooms authorized to be commercialized in Europe is very high. However, only 60 out of a total 268 fungal species are allowed to be cultivated. This highlights the importance of guidelines or legislation for safe business of wild mushrooms. The species richness and composition of the mushrooms listed for commerce is very heterogeneous within Europe [58].

In Spain the health conditions used for the production, transformation, and distribution of fresh mushrooms, besides preserved mushrooms for alimentary use and marketing, are established through the Real Decreto 30/2009, in January 16, 2009 [59].

Cadmium and lead are elements with high bioaccumulation from substrates in numerous

mushroom species. European Food Safety Authority (EFSA) has established the levels of lead and cadmium in foodstuffs. Maximum levels in mushrooms are 0.30 and 0.20 (mg/kg wet weight) for lead and cadmium respectively [60, 61]. Nevertheless, there is a consensus about the safety of most wild-growing mushroom species from unpolluted areas. This cannot be applied to the mushrooms from sites contaminated with the detrimental elements.

There are some information in the literature about the potentially procarcinogenic effect of hydrazines agaritine and gyromitrin, which are associated with *Agaricus* and *Gyromitra esculenta*, respectively. However, current evidence suggests that the consumption of cultivated *A. bisporus* poses no risk to healthy humans [62, 63].

FINAL CONSIDERATIONS

There is a global concern about health problems as cardiovascular disease, diabetes, obesity and cancer, which frequency have been reaching epidemic proportions around the world. Scientific literature highlights the power of certain nutrients and bioactive compounds present in ordinary foods, for preventing and treating specific pathophysiological conditions. In fact, wild edible mushrooms are traditionally used in many countries, not only for their sensory and nutritional aspects, but also due to their medicinal effects. However, not all the mechanisms involved in the health benefits of consuming mushrooms are fully understood, and some of them have yet to be confirmed in clinical trials.

Despite of the growing appeal for humans by their medicinal effects and nutritional value, mushrooms are also very cherished for their texture, savory flavor, and versatility in culinary. They can be easily incorporated into any kind of dish, improving the dietary diversity without adding many calories.

The information presented in this review point out that the positive effect of mushrooms on health is beyond basic nutrition. The consumption of mushrooms as a functional food could be a simple, but a promising way, to prevent or treat some health conditions. Therefore, it is very valuable expanding our knowledge about mushrooms, in order to identify all their active principles and the mechanisms involved in each health benefit, getting aware about the doses required to achieve that, in a safe range for humans.

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