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Health Benefits of Edible Mushrooms Focused on *Coriolus versicolor*: A Review

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Abstract

The biological properties present in mushrooms have been extensively studied. Besides nutritional properties, mushrooms have attracted market attention because they are a potential source of bioactive compounds able to perform several functions in organisms with benefits for consumer health. In recent years *Coriolus versicolor* aroused interest among researchers because of the bioactive properties demonstrated. Polysaccharopeptide (PSP) and polysaccharopeptide Krestin (PSK) have shown to be useful adjuncts to the therapy of cancer; these polysaccharides from *C. versicolor* have also shown prebiotic activity, stimulating the growth of probiotic bacteria. Furthermore, enzymes such as laccases produced by *Pleurotus eryngii* and *Ganoderma lucidium* can confer activity against HIV; lectins produced by *Pleurotus ostreatus* and *Ganoderma carpense* have shown anti-proliferative activity in tumour cells; superoxide dismutase present in some mushrooms has antioxidant activity. Secondary metabolites such as terpenes, steroids, anthraquinones and benzoic acid have also antitumour activity. This review article highlights the health-promoting potential of several mushroom species with special emphasis on *C. versicolor*.

Keywords: Polysaccharopeptide, Polysaccharopeptide Krestin, Health-promoting Potential, Bioactive Compounds, Prebiotic Activity

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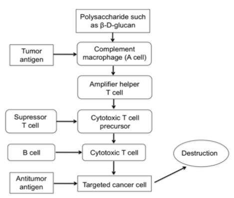

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1. Introduction

Mushroom cultivation has a long tradition mainly in Asian countries where it started centuries ago. Edible mushrooms constitute an element of human diet in many countries all over the world. At least 12000 species of fungi can be considered as mushrooms, and at least 2000 species are identified as edible [1]. According to Sánchez et al [2], among the 2000 edible mushroom species found in different regions of the world, only 35 are grown on a commercial scale and 20 are cultivated on an industrial scale. The most cultivated mushroom worldwide is *Agaricus bisporus* (button mushroom),

followed by *Lentinus edodes* (shiitake), *Pleurotus spp* (oyster mushrooms), *Auricula auricula* (wood ear mushroom), *Flamulina velutipes* (winter mushroom) and *Volvariella volvacea* [3].

Data reported by the Food and Agriculture Organization [4] indicate that in 2013 the world production of mushrooms was around 9.9 million tons. In the western countries mushrooms have been underestimated in nutrition field, although research has been demonstrating that mushrooms have low calorie content and high nutritive value. Edible mushrooms have high water content, for this only 5-15% of dry matter, which is mainly composed by dietary fibre and protein. They also contain vitamins B1, B2, D2, C, macro and microelements i.e. K, Mg, P, Zn, Fe and Cu [5].

Mushrooms have been used not only as a source of food, but also as medicinal resource. A total of 126 medicinal functions are thought to be produced by medicinal mushrooms, among which antitumour, immunomodulating, antioxidant, radical scavenging, cardiovascular, antihypercholesterolemia, antiviral, antibacterial, antiparasitic, antifungal, detoxification, hepatoprotective, and antidiabetic properties are the most recognized [6, 7, 8, 9]. These properties are conferred by bioactive compounds present in the mushroom and include polysaccharides, polysaccharide-peptide complexes, ribonucleases, lectins, protease inhibitors, lignocellulolytic enzymes, hydrophobins and superoxide dismutase that are present in the mycelium and fruiting body of the fungus [5, 10, 11]. Due to the health benefits demonstrated, some species of mushrooms have become attractive for development of functional foods and as a source of bioactive compounds towards the development of new drugs. Therefore, we will restrict our reviewi to one of the most important medicinal mushroom, *Coriolus versicolor*.

2. Coriolus Versicolor

Coriolus versicolor, also known in the literature by *Trametes versicolor* or *Polyporus versicolor,* belongs to the genus Coriolus, family Polyporaceae, order Polyporales and division Basidiomycotina [12]. This mushroom rise up from lignocellulosic wastes and has a fan-shaped wavy margin and may exist in nature in several different colours. Both extracellular and intracellular polysaccharides of *C. versicolor* are physiologically active as bioactive compounds. Two polysaccharides, polysaccharopeptide (PSP) and polysaccharopeptide Krestin (PSK) were isolated from *C. versicolor* and used as a supplement to support chemotherapy and radiotherapy of cancers due to its immunostimulatory properties [13, 14]. Furthermore, it seems that these polysaccharides may also act as prebiotics by stimulating the growth and/or activity of probiotic bacteria in the colon [15].

C. versicolor may be used in the extract or biomass forms. Extract forms (PSK and PSP) were extensively studied in past years. The biomass of *C. versicolor* is more resistant to proteolytic degradation and contains not only β-glucans but also other compounds with large clinical interest. The biomass form of *C. versicolor* contains a variety of relevant enzymes with different activities such as superoxide dismutase, peroxidase, glucoamylase, protease and laccase [16, 17, 18]. For example, this mushroom produces the enzyme laccase, which is a polyphenol oxidase belonging to the family of blue multicopper oxidases [19]. Laccase can oxidize a wide range of substrates, phenolic preferably. In the presence of mediators, the fungal laccases feature a wide range of substrates and then are able to oxidize compounds with a high redox potential. This enzyme has been used in biotechnology and industry, for the delignification of lignocellulose, bioremediation and sewage treatment [17].

Among the mushroom-derived compounds with therapeutic properties, the polysaccharides obtained from extracts of *C. versicolor* are the best known commercially. Both preparations (PSP and PSK) consist of β-glucans, polymers of D-glucose with β-1,3 and α-1,4 glycosidic linkages, but some of them can also contain arabinose, mannose, fucose, galactose, xylose and glucuronic acids. PSP and PSK extracted from *C. versicolor* typically contain 34-35% soluble carbohydrates, 28-35% protein, ~7% moisture, 6-7% ash and the remainder are free sugars and amino acids [20]. Among the 18 types of amino acids present, 70% consist of acidic and neutral amino acids such as aspartic acid, threonine, serine, glutamic acid, glycine, alanine, valine, and leucine [21]. Beneficial health properties reported over the years by Chinese and Japanese researchers have attracted the attention of the scientific community worldwide. Therefore, many clinical studies have been carried out in recent years with the aim to assess and identify the main bioactive properties of polysaccharides extracted from *C. versicolor.* These bioactive properties are detailed in Table 1.

The studies published so far have used extracts or polysaccharides isolated from the mushroom. However, the extract of the fruiting bodies is more susceptible to the action of proteolytic enzymes. The non-digestible property of the polysaccharides from *C. versicolor* make them potential prebiotic agents, but more studies are needed on this subject to efficiently validate its potential. Yu *et al.* [15] found that the presence of PSP from *C. versicolor* increased the levels of *Bifidobacterium* and *Lactobacillus* when *in vitro* studies were performed using the isolated polysaccharide form. They also identified an indirect effect in inhibiting pathogenic bacteria, including coliform and clostridia species, by lowering the pH. A study reported by Pallav *et al.* [22] demonstrated that the microbiome of volunteers randomly treated with PSP extracted from *C. versicolor* showed clear and consistent changes derived from a possible prebiotic activity.

Polysaccharides isolated from *C. versicolor* have demonstrated antitumour activity in the past [23, 24, 25]. *In vitro* studies showed that PSP acts selectively against certain tumour cells. Thus, it has been reported that *C. versicolor* extract, at the concentration of 1 mg/mL applied directly in human cancer lines, inhibited their growth namely gastric cancer, lung cancer, leukemia and lymphoma [26]. Moreover, PSP is active against Ehrlich ascites carcinoma, sarcoma 180 and leukemia P388. However, not all tumour cells appeared to respond to *C. versicolor* polysaccharopeptides [20].

Polysaccharopeptides are known as useful adjuncts to conventional therapy [27]. Some examples in animal models suggested an increase of chemo- or immunotherapy efficacy when they are associated to polysacacharides. The therapeutic use of *Coriolus versicolor* as an adjunct therapy in cancer treatment has been substantiated by numerous clinical trials [28, 29]. In human therapy, *C. versicolor* polysaccharopeptides are usually administered orally although, according to Yang *et al.* [25], PSK is effective orally, intravenously or intraperitoneally. A study carried out on mice [30] demonstrated that PSP has significant inhibitory effect on the tumour growth, inhibiting angiogenesis, which is an important process underlying tumour progression.

It was found that PSP significantly increased the number of monocytes ($CD14^+$/CD16) in *in vitro* studies. Thus, stimulating monocytes/macrophage function with polysaccharopeptides could be an effective therapeutic intervention in targeting tumours [31]. A study by Harhaji *et al*. (2008) has showed that *C. versicolor* methanol extract exerts pronounced anti-melanoma activity in mouse, both directly through antiproliferative and cytotoxic effects on tumour cells and indirectly through promotion of macrophage anti-tumour activity. All these studies indicated a great potential of polysaccharides from *C. versicolor* as base to develop new therapies for cancer [14, 33].

Significant literature support the immune and anticancer functions of *C. versicolor* PSP [30, 31, 32, 34]. According to Lee *et al.* [34] the culture duration affects the immunomodulatory and anticancer effect of polysaccharopeptide derived from *C. versicolor*. In this study, the extracts of PSP obtained at different days from *C. versicolor* culture were tested *in vitro* for their immune function on human normal peripheral blood mononuclear cells (PBMC) and cytotoxicity on human leukemia Molt 4 cells. Lau *et al.* [35] has carried out a study of the cytotoxic activities of *C. versicolor* extract on a B-cell lymphoma (Raji) and two human promyelocytic leukemia (HL-60, NB-4) cell lines using a MTT cytotoxicity assay. Results showed that *C. versicolor* extract selectively and dose-dependently inhibits the proliferation of lymphoma and leukemic cells possibly via an apoptosis-dependent pathway.

Recently, Luo *et al.* [36] showed that *C. versicolor* exhibited antitumour, anti-metastasis and immunomodulation effects in metastatic breast cancer mouse model, and could protect the bone from breast cancer-induced bone destruction. Another recent study by Yang *et al*. [41] characterized the imunopotentiating effects, which are related to the antitumour ability of the *C. versicolor* polysaccharides to bind and induce B cell activation using membrane Ig and TLR-4 as potential immune receptors.

In order to evaluate the pre-clinical and clinical evidence concerning the safety and effectiveness of the PSK as an adjuvant in the treatment of lung cancer, a recent review article examined thirty-one reports of 28 studies [43]. These results showed that PSK may enhance immune function, reduce symptoms of tumour-associated and prolong survival in lung cancer patients. Moreover, according to Fujita *et al*. [44] PSK may have an effect on the drug metabolizing enzymes in sarcoma-180 bearing mice, but not in normal mice.

Some studies have indicated that extracts of *C. versicolor* have antimicrobial activity against common pathogens such as *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Candida albicans*, *Klebsiella pneumoniae*, *Listeria monocytogenes* and *Streptococcus pneumonia*. The mechanism seems to be related with the activation of polymorphonuclear cells and an increased secretion of antimicrobial cytokines [45, 46].

Table 1. Bioactive properties in *Coriolus versicolor*

Bioactive properties	Bioactive compounds associated	Methodologies used in research	Reference
Antitumour activity	Polysaccharopeptide (PSP)	- These results indicate that IL-2 and PSP can slow progression of H238 tumours and that the mechanisms of action may be related to their direct cytotoxic effects, as well to their immunomodulatory properties;	[23]
		- It was found that PSP significantly increased the number of monocytes ($CD14^+/CD16^-$) compared to controls without PHA. This increase in monocytes was confirmed using another antibody panel of CD14 and MHCII;	[31]
		- Immunostaining of tumour tissues with antibody against the endothelial cell marker (Factor VIII) demonstrated a positive correlation in that both the vascular density and tumour weight were lower in mice treated with PSP;	[30]
		- Flow cytometry analysis on cell cycle and cell death (apoptosis) of Molt 4 cells indicated that the anticancer mechanism of PSP is related to its ability to induce S-phase cell arrest and apoptosis, respectively.	[34]
	Coriolus versicolor extract (CVE)	- CV extract at 50 to 800 Ag/mL dose-dependently suppressed the proliferation of Raji, NB-4, and HL-60 cells by more than 90 % ($p < 0.01$);	[35]
		- *C. versicolor* aqueous extract treatments resulted in remarkable immunomodulatory effects, which was reflected by the augmentation of IL-2, 6, 12, TNF-α and IFN-γ production from the spleen lymphocytes of CV-treated tumour-bearing mice.	[36]
	Coriolus versicolor methanol extract	- The results demonstrate that *C. versicolor* methanol extract exerts pronounced anti-melanoma activity.	[32]
Prebiotic activity	Polysaccharopeptide (PSP)	- *Trametes versicolor* contains putative prebiotic agents that alter human gut microbiota and pH;	[15]
		- PSP from *T. versicolor* acts as a prebiotic to modulate human intestinal microbiome composition.	[22]
Antioxidant activity	Polysaccharopeptide Krestin (PSK)	- PSK improved glutathione peroxidase activity through transcriptional induction of mRNA expression.	[37]
	Polysaccharide extracts	- The results of the study indicated that polysaccharide extracts of *G. applanatum*, *G. lucidum*, *L. edodes* and *T. versicolor* are antioxidative.	[38]
Antiviral activity	Polysaccharopeptide (PSP)	- PSP demonstrated inhibition of the interaction between HIV-l gp120 and immobilized CD4 receptor.	[39]
Antidiabetic activity	Intrecellular polysaccharides	- The α-glucosidase inhibitory properties were related to the presence of α-(1,4) glycosidic linkages in the polysaccharide structure and the total relative percentage of D-glucose and D-galactose in the structure of polysaccharides, other than triterpenoids;	[16]
	Polysaccharopeptide (PSP)	- PSP can competitively inhibit tolbutamide 4-hydroxylation in both pooled human liver microsomes and specific human CYP2C9 *in vitro*.	[40]
Immunoregulatory	*Coriolus versicolor* polysaccharide (CVP)	- CVP can bind and induce B cell activation using membrane Ig and TLR-4 as potential immune receptors. CVP activates mouse B cells through the MAPK and NF-B signaling pathways.	[41]
Memory improvement	*Coriolus versicolor* polysaccharide (CVP)	- The down regulation of GFAP further demonstrated that inflammation was reduced in the brain of AD mice following treatment. Moreover, the expression levels of superoxide dismutase and catalase were elevated in the brains of treated mice, indicating that oxidation levels were reduced upon the combination treatment.	[42]
Modulation of the inflammatory process in Alzheimer's diseases	Lipoxin A4 expressed by *Coriolus versicolor* biomass	- Activation of LXA4 signaling and modulation of stress-responsive vitagene proteins could serve as a potential therapeutic target for AD-related inflammation and neurodegenerative damage.	[8]

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Studies carried out with mice have shown that PSK increase the levels of glutathione peroxidase in macrophages [37]. Glutathione peroxidase is part of the first line of defense against lipid peroxidation, and protects the cell membrane in an early stage against attack by free radicals. Kozarski *et al*. [38] showed that polysaccharide extracts of *C. versicolor* have antioxidant activity. The extracts contained a mixture/complex of polysaccharides, proteins and polyphenols and the antioxidant effect measured was resistant to high temperatures. Another study developed by Santos Arteiro *et al*. [47] evaluated the antioxidant effect of the polysaccharides isolated from submerged cultures of *C. versicolor*. The radical scavenging for E-PPS (extracellular protein-polysaccharides) and I-PPS (intracellular protein-polysaccharides) produced per litre of culture was equivalent of 2.115 ± 0.227 and 1.374 ± 0.364 g of ascorbic acid, respectively. These complexes have revealed a positive effect protecting erythrocyte membranes from oxidation. They also demonstrated the ability to inhibit the synthesis of methemoglobin in stressed cells.

Submerged fermentation culture of *C. versicolor* showed potential antidiabetic activity [16, 48]. One of the drugs that have been used in the treatment of type II diabetes consists of α-glucosidase inhibitors. According to Hsu *et al.* [16] *C. versicolor* LH1 mycelia can inhibit the enzyme α-glucosidase. The α-glucosidase inhibitory properties were related to the presence of α-1,4 glycosidic linkages in the polysaccharide structure and the total relative percentage of D-glucose and D-galactose in the structure of polysaccharides. Furthermore, PSP inhibit tolbutamide biotransformation by cytochrome P450s enzymes in human liver [40].

The effect of PSP on the potential interaction of HIV-l and its target cell was investigated by Collins and Ng [39]. They demonstrated inhibition of the interaction between HIV-l gp120 and immobilized CD4 receptor by inhibiting the recombinant HIV-1 reverse transcriptase and a glycohydrolase enzyme associated with viral glycosylation.

The combination of Ginkgo Flavonoid (GF) and *C. versicolor* polysaccharide (CVP) in the prevention and treatment of a mouse model of Alzheimer’s disease was studied by Fang *et al.* [42]. A synergetic beneficial effect of GF and CVP has improved the memory in the mouse model providing new insights into the efficient utilization of traditional medicine for preventing dementia.

Recently, researchers have studied a protein expressed by *C. versicolor* biomass (lipoxin A4), which is able to modulate the inflammatory process involved in the Alzheimer's disease pathogenesis. This

study gives a positive view about possible therapeutic strategies for neurodegenerative damage [8]. A recent study developed by Barros *et al.* [49] tested the safety profile of biomass of *C. versicolor* in rats. Of the results obtained, it was possible to infer about the degree of safety for human consumption.

3. Health-promoting Potential of Edible Mushrooms

Recently, mushrooms have attracted much research interest because among other benefits they are a good source of β-glucans. Some properties such as molecular weight, chemical composition and the number of branches of side chains can determine the physical and therapeutic properties of β-glucans, providing specific biological properties to mushrooms. It was shown that they are a rich source of bioactive compounds such as polysaccharides, polysaccharide-peptide complex, proteases and lectins, exhibiting antitumour, antioxidant, antimicrobial, prebiotic and anti-inflammatory properties [5, 50, 52]. Furthermore, mushrooms also accumulate enzymes and secondary metabolites that may play important metabolic functions in the body. Studies carried out in recent years in order to discover and study bioactive compounds from mushrooms are summarized in Table 2, except those related with *C. versicolor*, previously detailed.

3.1. Antitumour Activity

Polysaccharides of mushrooms may have antitumour activity, which is associated with the immunostimulatory effect that they can exert, since they are foreign bodies to our immune system [53, 54, 55]. The immunostimulatory potential of glucans was recently summarized by Vannucci *et al*. [55]. This antitumour activity is not caused by a direct cytotoxic effect but via activation of the innate immune system of the host (Figure 1). The mechanism of action is related to the presence of pattern recognition receptors (PRRs) that can recognize the polysaccharides as pathogen-associated molecular patterns (PAMPs), due to its high molecular weight. Consequently, pro-inflammatory cytokines are secreted including tumour necrosis factor alpha (TNF-α), interleukin-1 (IL-1) and interleukin-6 (IL-6) which regulate the mechanisms against infections, recognition of foreign cells and tumour cells [5]. Some structures of the β-glucans seem to be better adapted to the PRR receptors, which suggests a relationship between the structure and antitumour activity of polysaccharides. Chang *et al*. [1] found that glucans with β-1,3 and β-1,6 linkages have higher antitumour activity.

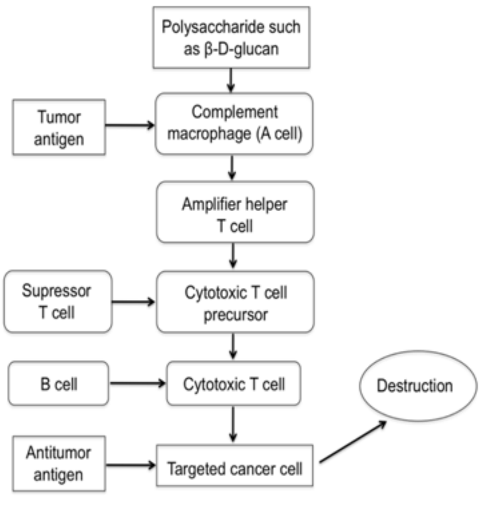

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Figure 1. Possible immune mechanism for β-D-glucan biological response modifier [56]

Table 2. Bioactive properties found in edible mushrooms

	Bioactive properties	Bioactive compounds associated	Methodologies used in research	References
Agaricus bisporus	Antioxidant activity	Gallic acid, protocatechuic acid, catechin, caffeic acid, ferulic acid and myricetin	- Ethanolic extract of *A. bisporus*; - Assay of antioxidant activity *in vitro* and *in vivo*.	[52]
	Immune system enhancer	Polysaccharide	- Bone marrow cell culture with GM-CSF; FACS analysis.	[59]
	Anticancer	______	- A hospital-based case–control study of breast cancer risk was conducted. All participants were Chinese women aged between 20 and 87 years.	[57]
Lyophyllum shimeji	Blood anticoagulant	A novel fibrinolytic enzyme: α- chymotrypsin	- Combination of anion exchange chromatography on a Mono Q 5/5 column and size exclusion gel filtration chromatography on Superdex 200 100/300 column.	[60]
Phallus indusiatus	Anti-inflammatory properties; Antioxidant capability	A β-D-glucan called T-5-N	- Desiccated fruiting bodies of *D. indusiata* (100 g) were extracted three times while avoiding direct sunlight by refluxing with 2000 mL of double distilled water at 90 ℃ with constant stirring at 400 ×g for 2 h. On cooling, the solution was centrifuged at 10 000 ×g for 30 min.	[61] [62]
Pleurotus eryngii	Antitumour activity; Immune system enhancer; Antibacterial activity	Acidic glycosphingolipids (AGLs)	- Animal experiments.	[63]
Hydnellum peckii	Anticoagulant	(2,5-dihydroxy-3,6-bis (4-hydroxyphenyl)-1,4-benzoquinone)	- Tests in albino rats; - *In vitro* anticoagulant evaluation; - Pharmacodynamic studies.	[64]
	Antibacterial activity	Atromentin and Leucomelone	- Structures were identified by various spectral analysis; - FabK assay.	[65]
Pleurotus ostreatus	Reduction of cholesterol levels	Lovastatin: inhibitor of 3-hydroxy-3-methylglutaryl Coenzyme A reductase	- Analysis of the inhibitor on a HPLC Knauer Lichrosphere 100 column.	[6]
	Anti-inflamatory activity	Oyster mushroom concentrate	- Electrophoretic mobility shift assay (EMSA)	[66]
Hericium erinaceus	Hemagglutinating activity	Glycoprotein HEG-5	- Isolation and purification in a DEAE-Sepharose Fast Flow anionic resin.	[67]
	Antibacterial activity against *Helicobacter pylori*	Polysaccharides (HEPs)	- Isolation of HEPs fractions by gradient ethanol precipitation; - Thin layer chromatography (TLC) and column chromatography.	[51]
	Anticancer potential against human gastrointestinal cancers	HE extracts (HTJ5 and HTJ5A)	- Animal experiments; - Antitumour activity was assessed by tumour growth inhibition (TGI).	[50]
Crucibulum laeve	Inhibition of the enzyme aldose reductase	A new salfredin-type metabolites (DSM 1653 and DSM 8519	- The structures were elucidated on the basis of UV-VIS spectroscopic, mass spectrometric and NMR spectroscopic evidence.	[68]
***Lentinula edodes* (Shiitake)**	Antioxidant	Polysaccharide	- The crude polysaccharide (LEP) was extracted by hot water from the fruiting bodies. Hydroxyl and Superoxide radical assay was used to determine the antioxidant activity.	[69]

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A recent study by Li *et al.* [50] showed that polysaccharide extracts from *Hericium erinaceus* are active against liver cancer cells *in vitro* and *in vivo*. According to Zhang *et al.* [57] the highest consumption of dietary mushrooms, including *Agaricus bisporus* and *Lentinula edodes,* is associated with a decreased risk of breast cancer in premenopausal women and postmenopausal women. *Grifola frondosa* is one of the most popular medicinal mushrooms. The levels of Natural Killer (NK) cell cytotoxic activity in cancer patients receiving D-fraction extracted from *G. frondosa* were monitored by Kodama *et al.* [58]. D-fraction markedly suppressed tumour growth, corresponding with increases in TNF-α and IFN-γ released from spleen cells and a significant increase in TNF-α expressed in NK cells. *Ganoderma tsugae* is the other medicinal mushroom in which polysaccharides have been well investigated in both the fruiting body and mycelia. Sixteen polysaccharides obtained from *G. tsugae* were examined for antitumour effects on Sarcoma 180 in mice.

The heteroglucan had a low tumour inhibition ratio, but caused a high survival ratio [70, 71, 72].

3.2. Antioxidant Activity

Polysaccharopeptides found in mushrooms can benefit general health by inducing enzymes that remove free radicals and reduce the oxidative damage. Many synthetic chemicals, such as synthetic phenolic compounds, are strong radical scavengers, but they usually have side effects. For this reason, natural antioxidants have been preferred for food applications [38] in particular due to the increasing demand of consumer by natural additives and ingredients. The antioxidant activities of ethanolic extract from edible mushroom *Agaricus bisporus* were evaluated by Liu *et al.* [52] and the results suggested that ethanolic extract of *A. bisporus* had potent antioxidant activity and could be explored as a novel natural antioxidant.

An analysis of the antioxidant capacity of *Phallus indusiatus* polysaccharides carried out by Ker *et al* [62] demonstrated a potent scavenging effect against oxygen free radicals. A study by Chen *et al*. [69] showed that the water-extractable polysaccharide fraction from *Lentinus edodes* exhibited significantly antioxidant activity against hydroxyl radicals, superoxide radicals and Fe^{2+} chelating ability.

Besides the antioxidant effect that polysaccharides may have, there are phenolic compounds naturally occurring in mushrooms. Total phenolic and flavonoid contents occurring in eight types of edible mushrooms (*Agaricus bisporus*, *Boletus edulis*, *Calocybe gambosa*, *Cantharellus cibarius*, *Craterellus cornucopioides*, *Hygrophorus marzuolus*, *Lactarius deliciosus* and *Pleurotus ostreatus*)

have been evaluated by Palacios *et al.* [73] with *C. cibarius* being the most effective against lipid oxidation and *A. bisporus* the species with lowest antioxidant activity.

3.3. Prebiotic Activity

The interest in the gut microbiome and host interaction is increasing. Initially, prebiotics were defined as non-digestible food ingredient that beneficially affects the host by selectively stimulating the growth of one or a limited number of bacteria in the colon [74]. In 2004, the concept has been updated as "selectively fermented ingredients that allow specific changes in the composition and/or activity in the gastrointestinal microbiota that confers benefits upon host well-being and health" [75].

The probiotics added to the foods are living microorganisms that must be kept alive and may be killed by heat, stomach acid or simply die with time. However, prebiotics are essentially dietary fibre and are not affected by heat, acid or time. Prebiotics act as food for probiotics. Furthermore, some health benefits of prebiotics (such as reducing glucose levels in the blood and improvement of the bowel function) have been medically proven and recognized by the European Food Safety Authority [76], [77].

Currently, inulin, fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS), lactulose and polydextrose are recognized as the well-established prebiotics in the market but there is evidence that the beta-glucans can also be a source of long chain prebiotics [78]. Synytsya *et al*. [7] indicated that mushroom extract of *Pleurotus ostreatus* and *Pleurotus eryngii* have a potential stimulator effect on the growth of probiotic bacteria. Later, a study carried out by Chou *et al.* [79] showed that a low concentration of polysaccharides from *Lentinula edodes*, *P. eryngii* and *Flammulina velutipes* may enhance the survival rate of *Lactobacillus acidophilus*, *Lactobacillus casei* and *Bifidobacterium longum* during cold storage.

According to Yamin *et al.* [80] polysaccharide mixtures from *Ganoderma lucidum* supported the growth of probiotics with population of *Bifidobacterium* and *Lactobacillus* genus with 0.3–0.7 and 0.7–1 $\log_{10}$ cells/mL increase, respectively. Giannenas *et al.* [81] investigated the consequences of consumption of *Agaricus bisporus* on turkey. The populations of total aerobes and anaerobes, *Lactobacillus* spp., *Bifidobacterium* spp., *Escherichia coli*, *Bacteroides* spp. and *Enterococcus* spp. were enumerated in ileum and caecum and the results showed that dietary mushroom inclusion beneficially affected performance and exerted changes in intestinal microbial communities.

3.4. Enzymes and Secondary Metabolites

Some species of mushrooms synthesize enzymes that may play important functions in the organism. *Pleurotus eryngii* and *Ganoderma lucidum* can produce laccases. In the human body this protein can confer activity against HIV by inhibiting the reverse transcriptase [82, 83]. The lectins produced by the species *Pleurotus ostreatus and Ganoderma carpense* have shown anti-proliferative activity on tumour cells [84].

Superoxide dismutase (SOD) is also present in some mushrooms. The recent interest in this enzyme is determined by its important physiological role in primary cellular antioxidant defense and its potential therapeutic use. Sabotic *et al.* [85] investigated the proteolytic potential of a large number of basidiomycetes. Proteolysis is an essential part of many physiological processes in all living organisms and basidiomycetes could prove to be a valuable source of proteases that could find use in biotechnological processes.

In addition to the presence of enzymes, mushroom low-molecular-weight secondary metabolites (such as terpenes, steroids, anthraquinones and benzoic acid) can regulate processes such as apoptosis, autophagy, angiogenesis, metastasis, cell cycle regulation, and signal transduction cascades that are associated with the development of cancer [86].

4. Conclusions

Nowadays mushrooms are used not only as a source of nutrients, but also as medicinal resources. Polysaccharides from mushrooms were reported to exhibit immunomodulation properties, antitumour, antioxidant, antimicrobial and prebiotic activity due to the greatest potential for structural variability in comparison with other biological active molecules.

An extremely large range of bioactive properties has been linked with the use of *C. versicolor* polysaccharides. Throughout the literature survey conducted to accomplish this review article, no studies were found using biomass from *Coriolus versicolor* mushroom to demonstrate bioactive effects. Two polysaccharides extracted from *C. versicolor* (PSP and PSK) have shown important biological properties during the past few years, and a special interest in researches in the area of cancer has aroused. It seems that *C. versicolor* polysaccharopeptide can be a useful adjunct to the therapy of cancer but, in certain cases, further work is necessary to prove some of the effects that have been observed *in vitro* and in experimental animal studies.

The role of prebiotics in improving human health has been extensively studied. It is hypothesized that prebiotic substances, like PSP and PSK found in *C. versicolor*, may be applied to modulate any microbial community to achieve advantageous effects. Furthermore, the antidiabetic, antimicrobial

and antioxidant activity demonstrated by studies carried out in *C. versicolor* indicate that this is a potential source of bioactive compounds that can bring important benefits to health.

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