β-Glucans: An Important Bioactive Molecule of Edible and Medicinal Mushrooms

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Abstract

Edible mushrooms are important for their dietary value and their biologically active and health promoting compounds such as polysaccharides, polysaccharopeptides and polysaccharide-protein complexes. Mushroom β-glucans such as β-glucan, Schizophyllan, Ganoderan, Lentinan and Pleuran are the components of the cell wall. They consist of glucopyranose molecules linked through β (1→3), β (1→4) or β (1→6) linkages. The mushroom β-glucans are not digested in human gastrointestinal tract and are thus considered as a potential source of prebiotics. β-glucans possess profound health promoting properties like speeding up the transit of bowel contents, increasing fecal bulk and frequency, consequently protecting the body from colon cancer, diverticular diseases and irritable bowel syndrome. They stimulate the immune system by having immunomodulatory, antitumour, antioxidant activities and are identified as biological response modifiers. Mushroom β-glucans differ in their nutraceutical effect due to the difference in their molecular masses, solubility, degree of polymerization, their structures and helical conformation. Various mushroom β-glucans are available as pure extracts in the market which are used as therapeutic agents, however, no commercialized functional products are available which have been enriched with mushroom β-glucans. Furthermore, it has a great potential to be used as an ingredient in the near future in various food industries, such as breakfast cereals, sport nutrition products, dairy products, bakery such as biscuits and breads, salad dressings and fat replacer. The aim of this review is to present information on β-glucans of edible and medicinal mushrooms, emphasize their benefits and the usage potential in the functional food and nutraceuticals.

Keywords: Mushrooms, β-glucan, bioactivity, functional, nutraceutical, food industry.

1. Introduction

β-glucans are polysaccharides of D-glucose monomers linked through β-glycosidic bonds. The structures of β-glucans and chemically modified β-glucans were given in Figure 1.

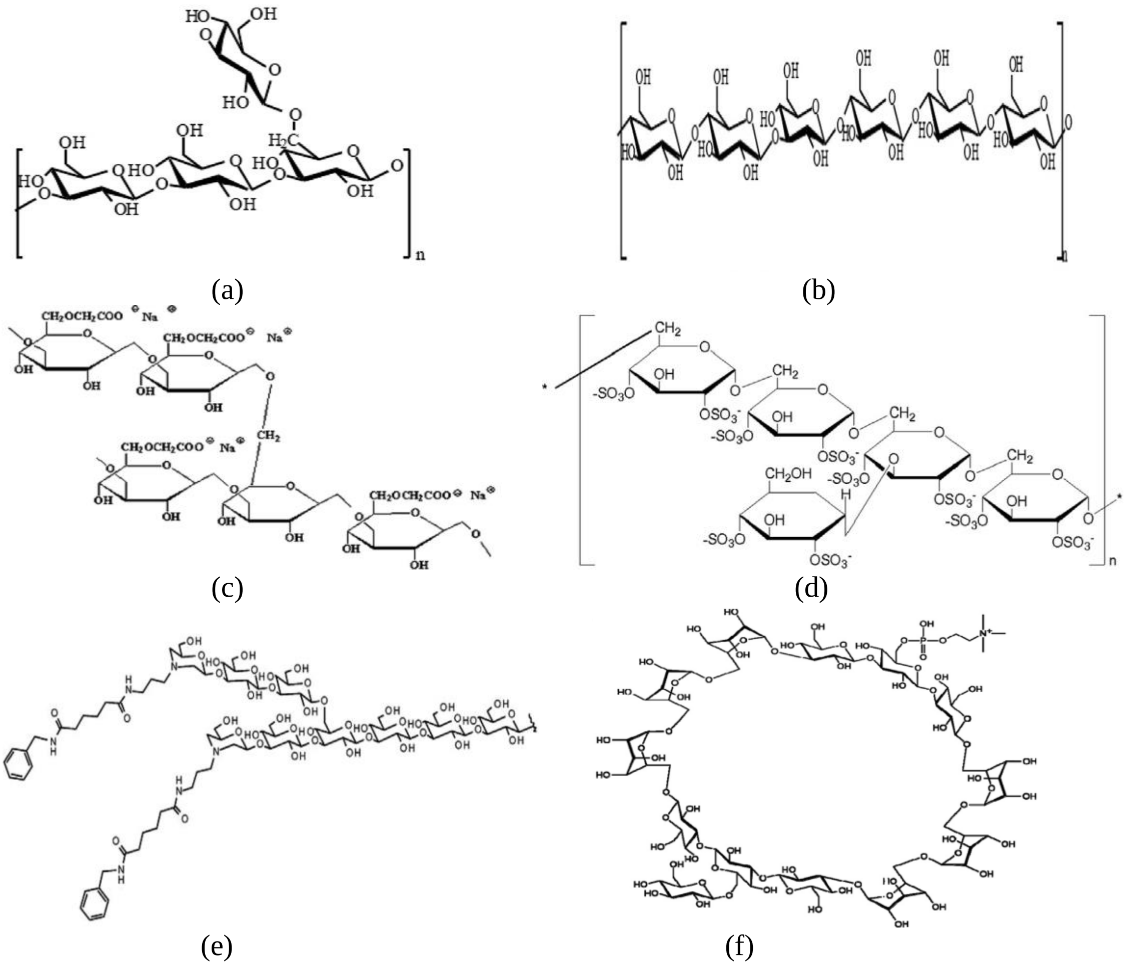

Figure 1. The structures of β-glucans and chemically modified β-glucans. (a) (1→3) β-glucans with ramifications β (1→6); (b) (1→3) β-glucans with ramifications β (1→4); (c) CM β-glucan; (d) Sulfated β-glucan; (e) Aminated β-glucan; (f) Cyclic glucan (Zhu et al., 2016).

As a kind of dietary fiber (DF), β-glucan could be found in a variety of natural sources such as yeast, mushrooms, bacteria, algae, barley and oat (Zhu et al., 2015). β-glucan exhibits a broad spectrum of biological activities including antitumour, immune-modulating (Rieder and Samuelsen, 2012), antiaging, antimicrobial, antioxidant and antiinflammatory properties. β-glucans have attracted attention because of their physical and chemical properties over the years. β-glucans from different sources and with different molecular weights have different biological activities (Du and Xu, 2014). Fungal β-glucan has been shown to be effective as an immune system booster and an antitumour substance (Du et al., 2015). The results of clinical research indicate that the presence of β-glucan is linked to the production and activation of macrophages, NK-cells, T-cells, B-cells from the body's natural defense system (Lindequist et al., 2005).

2. Mushroom β-glucans

Mushroom β-glucan is a carbohydrate polymer derived from the cell wall of mushrooms. β-glucan is known as biological response modifier (BRM), which refers to the ability to up-regulate and down-regulate the response of biological systems (Brown and Gordon, 2003; Novak and Vetvicka, 2009).

Mushroom β-glucans such as Schizophyllan, Ganoderan, Lentinan and Pleuran are the components of the cell wall. They consist of glucopyranose molecules linked through β (1→3), β (1→4) or β (1→6) linkages. Especially in Japan and China, Pleuran from *Pleurotus ostreatus*, Lentinan from *Lentinula edodes*, Schizophyllan from *Schizophyllum commune*, Grifolan (MD-fraction) from *Grifola frondosa* and Krestin from *Trametes versicolor* (PSK and PSP) in addition to the major cancer therapies like surgical operation, radiotherapy and chemotherapy are in clinical use for the adjuvant tumour therapy (immunotherapy) (Lindequist et al., 2005; Chan et al., 2009; Novak and Vetvicka, 2009).

β-glucans are also present in many other mushrooms such as *Auricularia auricula*, *Calocybe indica* (Calocyban), *Flammulina velutipes*, *Ganoderma lucidum* (Ganoderan/ Ganopoly), *Grifola frondosa*, and *Pleurotus abalones* (Lindequist et al., 2005; Villares et al., 2012; Zhu et al., 2015).

2.1. β-glucan Amounts in Mushrooms

Important medical mushrooms containing β-glucan as bioactive compound are seen in Table 1. The β-glucan contents of the mushrooms vary between 0.22 and 0.53 g/100 g on dry weight basis. According to Manzi and Pizzoferrato (2000), *Pleurotus pulmunarius* seemed to be the richest source of fungal β-glucans and it has been reported that *L. edodes* contains high levels of β-glucans in the soluble fraction. Camelini et al. (2005) found that *Agaricus brasiliensis* had higher (1→6)-β-glucan ratio and (1→3)-β-glucan increased with the maturation of fruiting bodies.

Table 1. Important medicinal mushrooms with β-glucans as bioactive components (Chan et al., 2009).

Mushroom species	Common name	β-glucan structure	Type of β-glucan
Agaricus blazei	Brazilian sun-mushroom, Himematsutake mushroom	Protein bound β-1,6-glucan	*Agaricus* polysaccharides
Coprinus comatus	Shaggy ink cap, lawyer's wig, or shaggy mane	β-1,3-glucan	*Coprinus* polysaccharides
Coriolus versicolor	Yun Zhi	Protein bound β-1,3;1,6-glucan	PSP (polysaccharide peptide) PSK (polysaccharide-Kureha or polysaccharide-K, krestin)
Ganoderma lucidum	Lingzhi, Reishi	β-1,3;1,6-glucan	*Ganoderma* polysaccharides, Ganopoly
Grifola frondosa	Maitake mushroom	β-1,3;1,6-glucan with xylose and mannose	Maitake D-Fraction
Lentinula edodes	Shiitake mushroom	β-1,3;1,6-glucan	Lentinan
Pleurotus ostreatus	Oyster mushroom, píng gû	β-1,3-glucan with galactose and mannose	Pleuran
Schizophyllan commune	Brazilian mushroom	β-1,3;1,6-glucan	Schizophyllan (SPG) or sizofiran

It was determined that Bracket fungi *Trametes versicolor, Piptoporus betulinus* or *Phlebia tremellosa* contained more than 50% β-glucans and in *Boletus edulis* (Bull. ex Fr., stipe part) or *Piptoporus betulinus* (Bull. ex Fr.) Karst. the amount was more than 50 g/100 g dw. In most of the wild mushrooms analysed, the β-glucan contents were significantly higher in stipes than in caps (Sari et al., 2017). Özcan and Ertan (2018) have determined that *Boletus edulis* is the highest β-glucan containing wild mushroom (13.93%). It was followed by *Cantharellus cibarius* and *Hydnum repandum* with 12.89 and 12.84% contents, respectively. Synytsya et al. (2008) working with *Pleurotus* spp. mushrooms found that the β-glucan content of the pilei was between 20.4-39.2% and the content of the stems was between 35.5-50.0%. The results of a study comparing the β-glucan content of some wild mushrooms (Sari et al., 2017) is presented in Table 2.

Table 2. β-glucan content of some wild mushrooms (not dividable in cap and stipe parts).

Mushroom species	Dry matter (%)	β-glucans (g/100g dm)	% β-glucans/ all glucans
Auricularia auricula (L.) Underwood	91.276	41.755±4.644	99.096
Fomes fomentarius (L.) Fr.	86.122	22.495±2.329	90.186
Grifola frondosa (Dicks. ex Fr.) Gray	92.783	25.991±3.643	83.761
Laetiporus sulphureus (Bull. ex Fr.) Murr.	89.627	47.006±6.517	89.345
Phlebia tremellosa (Schrad.) Nakasone & Burds.	96.547	53.555±2.452	98.572
Piptoporus betulinus (Bull. ex Fr.) Karst.	90.825	51.801±4.024	95.659
Trametes versicolor (L.) Lloyd.	87.892	60.788±11.795	99.337

2.2. Bioactive Properties of β-glucans in Mushrooms

Mushrooms polysaccharides having β-linkage have been demonstrated a boost in the human immune system and the modulation of the immunological response under certain conditions, thus they are commonly termed as biological response modifiers (BRM). As the result of the activation of the host's immune system, these polysaccharides show significant antitumour, antiviral and antimicrobial activities besides their other effects (Villares et al., 2012). A number of studies have been carried out on β-glucans that have a health-enhancing effect in various important ways such as antitumour and immunomodulatory (Table 3), antitumour, antiviral (Borchers et al., 2004; Moradali et al., 2007), cardiovascular (Wasser and Weis, 1999), liver protective, antiinflammatory (Lindequist et al., 2005), radioprotective (Pillai and Devi, 2013), antidiabetic (Kim et al., 2005), antioxidant (Deng et al., 2012), antibacterial (Beattie et al., 2010), and antiobesity activities (Zhang et al., 2013). Antitumour activity (Deng et al., 2012; Ren et al., 2012) and immunemodulating activity (Wasser, 2002) of mushroom β-glucans have been documented in the previous reviews. Basically, their health-promoting abilities are influenced by the molecular mass, branching configuration, conformation, and chemical modification of the polysaccharides (Ren et al., 2012). In terms of biological activity, β-1,3-D-glucans and β-1,6-D-glucans contained in oyster, shiitake, split gill, and himematsutake mushrooms, as well as other Basidiomycetes, are considered to be the most effective (Rop et al., 2009).

Table 3. Some mushroom β-glucans with antitumour and immunomodulatory activities (Zhang et al., 2007; Novak and Vetvicka, 2008; Kothari et al., 2018).

Mushroom species	Type of β-glucan	Character of polymer	Degree of branching
Agaricus blazei	β-glucomannan	Branched	-
Dictyophora indusiata	T-4-N, T-5-N	Branched	-
Ganoderma lucidum	Ganoderan	Branched	-
Grifola frondosa	Grifolan	Branched	0.31-0.36
Inonotus obliquus	Xylogalactoglucan	Branched	-
Laminaria spp.	Laminaran	Linear	-
Lentinula edodes	Lentinan	Branched	0.23-0.33
Pleurotus ostreatus	Pleuran (HA-glucan)	Branched	0.25
Poria cocos	Pachymaran	Linear	0.015-0.020
Schizophyllum commune	Schizophyllan	Branched	0.33
Sclerotinia sclerotiorum	Sclerotinan (SSG)	Branched	0.50

2.3. Extraction and Production of Mushroom β-glucans

The methods used to extract and produce β-glucans from various edible/medicinal mushrooms are given in Table 4.

Table 4. Production/extraction process of β-glucans from various edible/medicinal mushrooms.

Mushroom species	Production/Extraction process	References
Agaricus bisporus	Ultrasonic-assisted extraction, precipitation with ethanol, centrifugation	Tian et al., 2012
	Lyophilization, milled and submitted to successive cold and hot aqueous extraction	Smiderle et al., 2013
Agaricus brasiliensis	Sequentially extracted with 350 ml water, concentrated, dialyzed and DEAE-cellulose column chromatography	Camelini et al., 2005
	Lyophilization, milled and submitted to successive cold and hot aqueous extraction	Smiderle et al., 2013
Astraeus hygrometricus	Aqueous extraction, DEAE cellulose bag and Sepharose 6B column	Chakraborty et al., 2004
Boletus edulis	The estimation of non-starch glucans was based on the difference between glucose contents after total acidic hydrolysis of glucans and specific enzymatic hydrolysis of α-1,4-glucans	Özcan and Ertan, 2018
Boletus erythropus	Water extraction, centrifugation, DEAE Trisacryl M column and S 400 HR column	Chauveau et al., 1996
Botryosphaeria rhodina	β-glucan production were monitored in a stirred-tank bioreactor	Crognale et al., 2007
Cantharellus cibarius	The estimation of non-starch glucans was based on the difference between glucose contents after total acidic hydrolysis of glucans and specific enzymatic hydrolysis of α-1,4-glucans	Özcan and Ertan, 2018
Flammulina velutipes	Successive hot extraction with water and KOH and submitted to freeze-drying	Smiderle et al., 2006
Ganoderma lucidum	Extraction using dilute NaOH solution and Sephadex G-15 gel-filtration chromatography	Kao et al., 2012; Nie et al., 2013
Paenibacillus polymyxa	Seed culture was supplemented with carbon source to induce glucan production	Jung et al., 2007
Pleurotus eryngii	The estimation of non-starch glucans was based on the difference between glucose contents after total acidic hydrolysis of glucans and specific enzymatic hydrolysis of α-1,4-glucans	Synytsya et al., 2008
	Washing with ethanol and distilled water, extraction with boiling water, incubation with α-amylase, chemical deproteinization, dialization and lyophilization	Synytsya et al., 2009
Pleurotus ostreatus	The estimation of non-starch glucans was based on the difference between glucose contents after total acidic hydrolysis of glucans and specific enzymatic hydrolysis of α-1,4-glucans	Synytsya et al., 2008
	Washing with ethanol and distilled water, extraction with boiling water, incubation with α-amylase, chemical deproteinization, dialization and lyophilization	Synytsya et al., 2009
	Lyophilization, using of methanolic extraction, cold water, hot water, hot aqueous NaOH solutions, enzyme protease, and ethanol precipitation	Palacios et al., 2012
Ramaria botrytis	Hot water extraction followed by treating NaOH	Bhanja et al., 2014
Schizophyllum commune	Seed culture preparation, optimization of fermentation medium and schizophyllan production	Kumari et al., 2008
Termitomyces eurhizus	Hot alkaline extraction, centrifugation, DEAE cellulose bag and freeze dry	Chakraborty et al., 2006

The detection methods of β-glucan from mushrooms are summarized as: (1) enzymic method or McCleary method (Megazyme kit), (2) enzymelinked immunosorbent assay

(ELISA) method, (3) fluorimetric method with aniline blue, and (4) colorimetric method with Congo red (Zhu et al., 2015).

2.3.1 Extraction and Production of β-glucans from Fruiting Bodies of Mushrooms

Kim et al. (2005) extracted β-glucan from the fruiting bodies of *Agaricus blazei* using hot water for 3 h. Bhanja et al. (2014) extracted and isolated two water-insoluble glucans from fruiting bodies of *Ramaria botrytis*. Extraction in hot or boiling water is the most common and convenient method for extracting water-soluble fungal polysaccharides (Yan et al., 2014). Liu et al. (2014) obtained a purified β-glucan by precipitating a hot-water extract from fruiting bodies of *G. lucidum* with 20% (V/V) ethanol. The total carbohydrate content was 95.9% in prepared β-glucan.

2.3.2. Extraction and Production of β-glucans from the Mycelia of Mushrooms

Kim et al. (2009) provided a method for mass production of β-glucan from *S. commune*, comprising subjecting mycelia of *S. commune* to liquid culture with an addition of a synthetic adsorbent. In another study, a neutral polysaccharide, GLSA50-1B, was isolated from sporoderm-broken spores of *G. lucidum*, by hot-water extraction, graded ethanol precipitation, anion-exchange chromatography, and gel permeation chromatography (Dong et al., 2012). Kim et al. (2013) demonstrated generation of high β-glucan producing mutant strains of *Sparassis crispa*, additional culture optimization further increased β-glucan productivity of the mutant strains. Recently, Park et al. (2014) enhanced the β-glucan content in the sawdust-based cultivation of cauliflower mushroom (*Sparassis latifolia*) using three kinds of enzymes (chitinase, β-glucuronidase, and lysing enzyme complex) as elicitors.

2.4. Chemical Modification and Purification of Mushroom β-glucans

β-glucan is an important bioactive compound for human health, but its low solubility has led to the development of chemical modification technologies to improve bioavailability. Several methods to modify β-glucan are laid out to improve their functional and technological properties via physical and chemical crosslinking reactions (Ahmad et al., 2015). In this respect, β-glucans can be chemically modified to obtain various derivatives with potential industrial or medicinal importance (Synytsya and Novak, 2013).

Ion-exchange chromatography and gel filtration chromatograph are the most common and convenient methods for purifying polysaccharide. In general, the crude polysaccharide extracts were further applied to a Sephadex column and eluted with water (Zhu et al., 2015).

3. Studies on Mushroom β-glucan for Food and Nutraceutical Applications

3.1. Food Applications and Some Patents

There have been some studies previously conducted by enriching a product with the mushroom β-glucan agglomerated as food additive. β-glucans from *P. ostreatus* and *L. edodes* have been demonstrated satisfactory results when they were added to yogurt (Hozova et al., 2004) were used in the production of extruded snack products with low glycemic index (Brennan et al., 2013). Also chicken burgers were enriched with *P. sajor-caju*, fiber and β-glucans (Wan Rosli et al., 2011) as well as *P. ostreatus* was incorporated into sausages in an effort to lower their fat content (Chockchaisawasdee et al., 2010). In a study to produce a novel high-fibre and low-calorie functional food, Kim et al. (2011) used β-glucans from *L. edodes* as a wheat flour substitute in baked foods. These glucans improved the pasting properties of wheat flour and increased batter viscosity and shear-thinning elasticity without any adverse effect on air holding capacity or hardness. β-glucans of *Ganoderma amboinense, Agaricus* or *Fomes yucatensis*, or mixed mushrooms have also been tested for encapsulation of pickling liquid to be released in soups or sauces during cooking (Watanabe, 2005).

3.2. Nutraceutical Applications, Some Clinical Studies and Patents

“Mushroom nutraceuticals” is nowadays a relatively common term which refers to a refined polysaccharide, or a partially refined fruit body extract, or the dried biomass from mycelium or the fruiting body of a mushroom, which is consumed in the form of capsules, tablets, powder, syrups, solutions as a dietary supplement with some therapeutic properties (Giavasis, 2014). Camelini et al. (2005) investigated the β-glucans of *A. brasiliensis* in different stages of fruiting body maturity and their use in nutraceutical products. The results showed that because of their important glucan contents, mature fruiting bodies of *A. brasiliensis* should be used for nutraceutical products. Cap-opened, more fragile mature fruiting bodies of *A. brasiliensis* should be selected over immature ones for the production of nutraceuticals. Synytsya et al. (2008) reported that the stems of *Pleurotus eryngii* and *P. ostreatus* could be used for the preparation of biologically active polysaccharide complexes as food supplements. Schizophyllan, produced by *S. commune* ATCC 38548 has attracted attention as immunomodulatory and anti-neoplastic agent in pharmaceutical industry in the recent years (Kumari et al., 2008). Akiyama et al. (2011) studied the effects of agaritine, a hydrazine-derivative from hot-water extract of *A. blazei* Murrill on human leukemic monocyte lymphoma (U937) cells. Agaritine induced DNA fragmentation, annexin V expression, and cytochrome C release. Caspase-3, 8 and 9 activities were gradually increased after agaritine treatment. *A. blazei* has been used as an adjuvant in cancer chemotherapy and various types of anti-leukemic bioactive components have been extracted from it (Patel and Goyal, 2012). It was proposed to mix β-glucan from mushroom with one or two substances such as ubiquinone Q10 and ferments leading to a biologically active additive for food with a wide range of action (Bragintseva et al., 2002). Suga et al. (2005) suggested converting lentinan into superfine particles, improving absorption through mucosa.

In animal experiments, β-glucans have been shown to have varying activity against sarcomas, mammary cancer, some chemically induced cancers, adenocarcinoma, colon cancer and some leukemias. Lentinan has already been shown effective in gastric carcinomas (Taguchi et al., 1985; Jeannin, et al., 1988). Furthermore, lentinan was reported to induce apoptosis in murine skin carcinoma cell-lines (Gu and Belury, 2005). Even if mushrooms and especially β-glucans have been used in Chinese medicine for decades, mechanisms need to be elucidated. However, lot of these substances have already been patented for antitumour treatments. Among them, β-glucan extracted from *Agaricus* mushroom was proposed, together with fucoidan (Hosokawa, 2003). The use of *Grifola frondosa* extract has also been patented, mixed with fucoidan and organic germanium (Sogabe, 1998).

Extracts of *L. edodes* markedly inhibited the growth of Sarcoma 180 (a retrovirus, similar to HIV which uses reverse transcriptase for its tumourpromoting activity) (Chihara et al., 1987). According to clinical studies, lentinan produces specific T-helper cell stimulation in healthy humans as well as animals. It has also been recognized to stimulate lymphokine activated killer activity in combination with Interleukin-2 (Suzuki et al., 1990). Other patents concerning direct utilisation of β-D-glucans such as *G. frondosa* extract (Sogabe, 1996) for treating AIDS have been rare.

In 2003, an original application has been patented, proposing to use β-glucan as a gene carrier (Sakurai et al., 2003). In this patent, a hydrogen-bonding polymer with a triple-helix structure (such as schizophyllan, curdlan, lentinan, scleroglucan) was used for binding to a nucleic acid. Thus, a nucleic acid-polymer complex was obtained and could be applied as a vector. Moreover, this complex was also resistant to nuclease, allowing its use as a nucleic acid-protecting agent. PSP derived from *Coriolus versicolor* (syn. *Trametes versicolor*), a Chinese product commercially available since 1987 (Cui and Chisti, 2003), has been documented to improve the quality of life in cancer patients by providing substantial pain relief and enhancing immune status in 70-97% of patients with stomach, esophagus, lung, ovary and cervical cancers. Both PSK and PSP boosted immune cell production, ameliorated chemotherapy symptoms and enhanced tumour infiltration by dendritic and cytotoxic T-cells (Kidd, 2000). From a commercial standpoint, pleuran from oyster (*P. ostreatus*) mushrooms and lentinan from Shiitake (*L. edodes*) mushrooms are currently the most frequently used β-glucans. Both of them show positive effects on the intestines. They increase the resistance of intestinal mucosa to inflammation (Zeman et al., 2001) and inhibit the development of intestinal ulcers (Nosalova et al., 2001). Lentinan also shows a positive effect on peristalsis (Van Nevel et al., 2003).

3.3. Industrial Food Applications of Mushroom β-glucan in Functional Foods and Dietary Supplements

According to literature data, β-glucan has the potential to perform functions in the food industry such as thickening, water-holding, or oil-binding, gelling, film-making and encapsulation agent, and emulsifying stabilizer (Ahmad et al., 2012a, b; Giavasis, 2013; Zhu et al., 2016). Today, mushroom-glucans are found in the market more in the form of capsules or tablets as food supplements and to a lesser extent as ingredients in the food products (Eleftherios et al., 2014). In addition to food, β-glucans have potential applications in medicine and pharmacy, cosmetic and chemical industries, in veterinary medicine and feed production (Laroche and Michaud, 2007; Zhu et al., 2016). Besides, various mushroom β-glucans are available as pure extracts in the market which are used as therapeutic agents. *S. commune* glucan manufactured by Bioland Technology Co. Ltd. is commercially available in the market (Zhu et al., 2016). There have been two patents on production technology of β-glucan from *S. commune*, today (Kim et al., 2008; 2009). Polysachharides such as lentinan, schizophyllan from shiitake and Schizophyllan mushrooms, PSK and PSP, the protein bound polysachharides from turkey tail mushroom, have been developed as anticancer agents in Japan and are now available worldwide (Lull, et al., 2005). There has also been a patent on application on β-glucan process, additive and food product (Cahill et al., 2003). Although some of the most studied polysaccharides produced by mushrooms (e.g. schizophyllan and lentinan) are already available and marketed as nutraceuticals (pharmaceutical formulation), their addition to food in their purified form has not been commercialized, yet (Giavasis, 2013). Nevertheless, β-glucan has a great potential to be used as an ingredient in the near future in various food industries, such as breakfast cereals, prebiotic sausage formulations, sport nutrition products, dairy products such as yogurts, bakery products such as biscuits, breads, cakes and ready-to-eat snacks, beverages, salad dressings and fat replacer that have some functionalities such as noticeable effect on physical and sensory properties, calorie-reducing and cholesterol-lowering actions and faster proteolysis, lower release of large peptides and a higher proportion of free amino acids, the glycemic response manipulation, controlling food intake and reducing 24 h energy intake and having good quality characteristics (Zhu et al., 2016).

The polysaccharides extracted from *A. brasiliensis*, *C. sinensis*, *G. lucidum*, *G. frondosa*, *L. edodes*, and *T. versicolor* are used to produce tablets for inhibiting the growth of tumours and improving the immunity (Rai et al., 2005). Several mushroom products, mainly polysaccharides such as β-D-glucans, have also proceeded successfully through clinical trials and are used as drugs to treat cancer and chronic diseases (Morris et al., 2016).

Today, it is possible to find commercial dietary supplements originated from various mushroom β-glucans in the form of powdered extracts, tablets, capsules, teas and syrups on the market. Imunoglukan P4H® from *P. ostreatus*, LentinanXP in USA/Lentinex® in Europe and Shiitake Gold and Pure Shiitake™ from *L. edodes*, Ganopoly® and Immulink MBG® from *G. lucidum*, D-fraction, MD fraction, MaitakeGold 404® nutraceutical extract and Pure Maitake™ from *G. frondosa*, Pure Turkey Tail™ from *T. versicolor* and Immune Assist™ from *A. blazei*, *C. sinensis*, *G. lucidum*, *G. frondosa*, *L. edodes* and *T. versicolor* can be given as example (Point Institute, 2013; Morris et al., 2016; Reis et al., 2017; URL-1, 2018). McCleary and Draga (2016) developed a robust and reliable method for the measurement of β-glucan in mushroom and mycelial products. In the literature, there have also been some clinical studies on pharmacological benefits and safe doses of these mushroom β-glucan derived dietary supplements such as Lentinex® (Gaullier et al., 2011) and Imunoglukan P4H® (Jesenak et al., 2012). A scientific documentation was published to carry out the additional safety assessment for Lentinex®, an aqueous mycelial extract of *L. edodes*, as a novel food ingredient (EFSA, 2010). On the other hand, Gründemann et al. (2015) have reported that the standardisation of shiitake preparations is difficult because even preparations with similar polysaccharide and β-glucan contents have different immunological properties.

4. β-glucan Market by Food & Beverage Applications and Regions

The industries are adopting β-glucan to fortify foodstuff with high dietary fibres as consumer interests in the nutraceutical products is on escalation. Furthermore β-glucan actively impacts the metabolic parameters and help curing the chronic diseases. The worldwide development of policies for inclusion of functional ingredients in industrial products boosts the global β-glucan market. According to application segmentation, food and beverage segment was accounted more than 25% value share in 2016. Increasing demand for fibrous intake and concerns over blood cholesterol levels majorly drives the β-glucan market in food and beverage applications. In addition, β-glucan allows food product manufacturers to attract attention heart health claims in functional foods such as heart healthy biscuits, dairy products, snack bars etc., which in turn aids in driving the global β-glucan market (URL-2, 2018).

Geographically, the Europe accounted major share in the global β-glucan market in 2016. Approval of health claims by EU, related to heart health, blood glucose, cholesterol control and digestive health will be fueling the growth for β-glucan market in the region over the forecast period. In Asia Pacific, the government initiatives for awareness on cancer, women heart and maternal health are expected to drive the sales revenue of β-glucan during the forecast period of 2017-2025 (URL-2, 2018).

5. Conclusion

Although there are many findings related to the biological effects of β-glucans *in vitro* and *in vivo*, there are still some questions about structure activity and dose activity relationships. Moreover, β-glucan content of mushroom products has not been standardised, yet. To make better use of β-glucan, food manufacturers and processors must bring attention not only to ensure sufficient concentration of β-glucan in the raw material but also to the processing methods and physicochemical properties of β-glucan, decreasing mechanical and enzymatic breakdown of the β-glucans in end-product and optimizing processing conditions. Mushroom β-glucans have potential nutraceutical properties that could be explored in the food and the pharmaceutical fields and might present different functional properties upon modification through suitable means and continuity of detailed clinical studies for the convinience of consumers.

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