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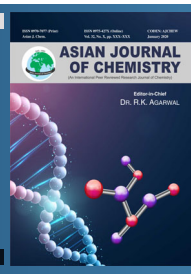

REVIEW

Bioactive Glucans from Edible Mushrooms: A Review

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Health promoting glucans are natural polysaccharides obtained from fungi, yeast, bacteria and plants. The glucans showed different pharmacological activities like immunomodulatory, antibacterial, antiviral and antitumor/cancer effects. A high level of biological activity was found in glucans, especially β-(1→3)-D-glucans, β-(1→6)-D-glucans and β-(1→3), (1→6)-D-glucans from some edible mushrooms and branched glucans having large molecular weights can also activate immune cells. The (1→3)-β-glucans are attractive materials not only in biotechnology but also in nanotechnology due to its strong helix-forming character. This review summarized the available knowledge of the structure of glucans, along with biological activities from different mushrooms.

Keywords: Glucans, Polysaccharides, Mushrooms, Bioactive.

INTRODUCTION

Mushroom consumption now a day's has remarkably increased for health concious people. It has been used as a delicious food or food flavoring materials and fresh as well as preserved mushrooms are consumed in many countries [1]. Edible mushrooms are highly nutritious [21] and used as a source of physiologically beneficial and non-toxic medicines [3]. Mushrooms show favourable dietetic properties due to their low caloric value, low fat content and high levels of proteins, minerals and polysaccharides [4,5].

Mushroom polysaccharides, especially glucans, have diverse biological activities such as antitumor, immunomodulatory, anti-coagulant, hypoglycemic and antiviral properties [6-8]. Thus the mushroom polysaccharides have drawn the attention of chemists and biologists for searching of new drugs. It has been reported that several glucans like (1→3)-β-D-glucan [9,10], (1→3)-β-D-glucan [11,12], (1→3)-β, (1→4)-β-D-glucan [13], (1→4)-, (1→6)-β-D-glucan [14], (1→3)-(1→6)-β-D-glucan [15,16], (1→3)-, (1→6)-β-D-glucan [14], (1→6)-β-D-glucans [17] α and β-D-glucan-protein complex [18,19] showed antitumor and immuno-stimulating properties. Different polysaccharides from higher basidiomycetes group are effectively used as food additives and dietary supplements, which should strengthen the immune system of humans. The role of molecular weight in the biological activity of glucans is very important. The content of β-glucan is depend on many factors, such as species, growing conditions of mushrooms, the degree of fruiting body maturity and total dietary fibre content, *etc*.

Due to its biocompatible properties, β-glucans as coating materials are exploring in the field of nano-biotechnology. The β-(1,3)-glucan can interact with single-walled carbon nano tubes to from unique nanocomposites for acting as novel one-dimensional hosts for DNA/RNA [20]. The glucan from *Pleurotus florida* (cv. florida) was used to prepare gold nanoparticles [21], where glucan acts as reducing as well as stabilizing agent and showed catalytical activity. Antibacterial silver nanoparticles were synthesized using glucan isolated from a mushroom *Pleurotus florida* blue variant [22]. The main objective of this review is to present finding on sources, structural features, extraction, purification and biological properties of glucans from edible medicinal mushroom.

Glucans from mushrooms: Mushroom is the main source of especially for β-glucan (except cellulose). The major components are (1→3)-β-D-glucan, (1→6)-β-D-glucan (1→3)-α-D-glucan, chitin and glycoproteins were found in the cell walls

of mushrooms [23]. The existence of β-glucan was proven in the cell wall of *Saccharomyces cerevisiae* by Bell and Northcote [24]. Several D-glucans were extracted from different edible and also some non-edible mushrooms through either hot water extraction or alkaline extraction process. On the basis of their chemical structure and intermolecular interactions, glucans can act as immunomodulator or immunoactivator. Among the polysaccharides, homo and hetero glucans, with β-(1→3), β-(1→4) and β-(1→6)-glycosidic linkages were supposed to play a key role in different health aspects of mushroom [25]. (1→3)-β-Glc*p* backbone and (1→3),(1→6)-β-Glc*p* are the majorly found in mushroom β-glucans [26]. The different structural features of bioactive β-glucans from mushrooms [27-53] are shown in Table-1.

Glucans from hybrid mushrooms: Developments of new hybrid stains through para-sexual mating are needed not only

TABLE-1
SOURCE, STRUCTURAL FEATURES AND BIO-ACTIVITY OF GLUCANS FROM MUSHROOMS

Source (Mushroom)	Structural features	Biological activity	Ref.
Pleurotus djamor	(1→3)-β-D-Glc	Cytotoxic activity against PA1 ovarian carcinoma cell	[27]
Pholiota nameko	(1→3)-β-D-Glc main chain & (1→6)-β-D-Glc branches	Inhabited the inflammatory pain	[28]
Fomitopsis betulina	(1→3),(1→6)-β-D-Glc (soluble, branched) (1→3)-α-D-Glc (insoluble, linear)	Immuno-modulator	[29]
Meripilusgiganteus	(1→3,6),(1→6)- β-D-Glc, with terminal α-D-Glc & (1→6),(1→4,6)-α-D-Glc with terminal β-D-Glc	Antioxidant activity	[30]
Entoloma lividoalbum	(1→3,6)-β-D-Glc, (1→3)-β-D-Glc, (1→6)-β-D-Glc with terminal β-D-Glc	Antioxidant & Immuno-modulator	[31]
Lentinus edodes	(1→3)-β-D-Glc main chain & (1→6)-β-D-Glc branches	Produce cytokines &induce apoptosis of S180 cells	[32]
Russula albonigra (Krombh.)	Terminal β-D-Glc, (1→3)-β-D-Glc, (1→6)-β-D-Glc & (1→3,6)-β-D-Glc (1:2:2:1)	Act as Antioxidant & Immunostimulant	[33]
Entoloma lividoalbum	Terminal β-D-Glc, (1→3)-β-D-Glc, (1→6)-β-D-Glc &(1→3,6)-β-D-Glc (1:3:2:1)	Antioxidant activity	[34]
Antrodia camphorata	(1→3)- β-D-Glc	Exhibited a selective cytotoxic effect on BxPC-3 human pancreatic cancer cells	[35]
Tricholoma crassum (Berk) Sacc.	(1→3)-β-D-Glc, (1→6)- β-D-Glc, (1→3,6)- β-D-Glc &Terminal β-D-Glc (1:2:1:1)	Enhancing, stimulating the immune system & inhibition activity towards lipid peroxidation	[36]
Dictyophora indusiata	(1→3)- β-D-Glc with (1→6)- β-D-Glc side branches (Triple helical conformation.)	Cytotoxicity against S-180 cells in vitro but showed anti-tumor activity *in vivo*	[37]
Ramaria botrytis	(1→6)- β-D-Glc with (1→3)- β-D-Glc branching	Immuno-enhancing properties	[38]
Macrolepiota dolichaula	(1→3,6),(1→6),(1→4), (1→3)-linked & terminal β-D-Glc (1:2:1:1:1)	Immuno-enhancing properties	[39]
Agaricus bisporus & Agaricus brasiliensis	(1→6)- β-D-Glc	Immunostimulatory activity on human THP-1 macrophages	[17]
Coriolus versicolor	Protein bound polysaccharide, β-glucan	Phagocytic activity Phosphorylation of Akt and CK2& Ikaros activity	[40]
Termitomyces robustus (var.)	(1→6)- β-D-Glc (Soluble); (1→3)- β-D-Glc,(1→3,6)-β-D-Glc with terminal β-D-Glc (Insoluble)	Immuno stimulator	[15]
Calocybe indica	(1→6)- β-D-Glc,(1→4)- α-D-Glc, (1→4,6)-β-D-Glc with terminal α-D-Glc (2:2:1:1)	Immuno stimulator	[41]
Russula albonigra (Krombh.)	(1→3)- β-D-Glc,(1→3,6)- β-D-Glc,(1→3)- α-D-Glc with terminal α-D-Glc(1:1:2:1)	Immuno-enhancing properties	[42]
Lentinus edodes	(1→3)- β-D-Glc, with (1→6)- β-D-Glc side chain four glucans:LNT-H, LNT-S,LNT-E,LNT-B)	Supression of LPS-induced NO from macrophage RAW264.7 cells	[43]
Ganoderma lucidum	(1→6)-β-D-Glc back bone, (1→4)-linked residue	Used as a supplement in Antitumor therapies	[44]
Grifola frondosa	(1→3),(1→6)-β-D-Glc,	Inhibited tumor growth	[45]
Pleurotus sajor-caju	(1→3), (1→6)-β-D-Glc (Gel like glucan)	Immunological activity	[46]
Schizophyllum commune	Mixture of α, β-(1→3)-D-Glc	Antioxidant activity	[47]
Lentinus squarrosulus (mont.)	(1→3)- β-D-Glc, (1→6)- β-D-Glc,(1→3,6)-β-D-Glc with terminal β-D-Glc (2:1:1:1)	Immuno-enhancing properties	[48]
Lentinus edodes	β-(1→3): β-(1→6) glucan.	Anticancer activity against human esophageal cancer cell line	[49]
Pleurotus florida,cv Assam florida	(1→3)- α-D-Glc (1→3)- β-D-Glc, (1→6)- β-D-Glc, (1→3,6)- β-D-Glc, terminal α-D-Glc (1:1:1:1:1)	Immuno-enhancing properties	[50]
Armillariella tabescens	(1→6)- α-D-Glc,(1→4)- β-D-Glc,	Antitumor activity	[51]
Agaricus blazei	α-(1→4)-: β-(1→6)-D-Glc, α-(1→6)-: α-(1→4)-D-Glc, β-(1→6)-: β-(1→3)-D-Glc, β-(1→6)-: α-(1→3)-D-Glc,	Potential therapeutical benefits for use in nutraceutical products	[52]
Poria cocos	β-(1→3): β-(1→6)-D-Glc	Antitumor activity	[53]

TABLE-2
SOURCE, STRUCTURAL FEATURES AND BIO-ACTIVITY OF GLUCANS FROM HYBRID MUSHROOMS

Source (Mushroom)	Structural features	Biological activity	Ref.
Hybrid (*pfle1v*) of *P. florida* and *L. edodes*	(1→3,6),(1→6), (1→3)-linked β-D-Glc & terminal β-D-Glc (1:2:2:1)	Immuno-modulator	[58]
Hybrid (*pfls1h*) of *P. florida* and *L. squarrosulus.*	(1→3,6),(1→3), (1→6)-linked β-D-Glc & terminal β-D-Glc (1:1:1:1)	Immuno-logical activity	[59]
Hybrid (*pfloVv5fb*) of *V. volvacea* & *P. florida*	(1→3,6),(1→6)-linked β-D-Glc & terminal β-D-Glc (1:2:1)	Immuno-logical activity	[60]
Hybrid (*pfle1r*) of *P. florida* and *L. edodes*	(1→3,6),(1→6)-linked β-D-Glc & terminal β-D-Glc (1:3:1)	Immuno-enhancing properties	[61]
Hybrid between *PfloVv12* and *V. volvacea*	(1→6)- β-D-Glc (Water soluble); (1→3), (1→3,4)-linked β-D-Glc & terminal β-D-Glc (Water insoluble) (1:1:1)	Immuno-enhancing & antioxidant properties	[62]
Hybrid of *P. florida* and *C. indica* (APK2)	(1→6),(1→4,6)-linked β-D-Glc (1→4)- α-D-Glc & terminal α-D-Glc (3:1:1:1)	Immuno-enhancing & antioxidant properties	[63]
Hybrid of *P. florida* and *V. volvacea*	(1→6)- β-D-Glc	Immuno-enhancing properties	[64]

to understand mushroom biodiversity but also for the genetic improvement with respect yield, quality, temperature tolerance, bio-efficacy of commercial mushrooms. Nine intergeneric somatic hybrids (*pfle*) were produced through protoplast fusion between *Pleurotus florida* and *Lentinula edodes* using double selection method [54]. Twelve inter-generic somatic hybrids (*pfle*) were obtained through PEG-mediated protoplast fusion between *Pleurotus florida* and *Lentinula edodes* [55] and the production of somatic hybrid was done between *Calocybe indica* var. (APK2) and *Pleurotus florida* [56] through PEG-mediated protoplast fusion. Through intergeneric protoplast fusion between *Volvariella volvacea* and *Pleurotus florida*, twelve somatic hybrid were produced [57].

Several glucans were isolated from hybrid edible mushroom and characterized their structural nature and biological activity (Table-2). The structural natures of the repeating units of the glucans from hybrid mushroom are quite similar to natural mushroom. Here, branched β-glucans containing (1→3,6/4), (1→6), (1→3)-linked β-D-Glc and terminal β-D-Glc [58-64] were obtained mainly and linear (1→6)-β-D-glucan was also reported [62,64]. An α,β-D-glucan also reported [63], where different mode of linkages was found and the backbone of the glucan was the (1→6)-β, (1→4)-β and (1→4)-α linked-D-Glc*p*. These β-glucans have been observed as immuno-enhancing and antioxidant agents [58-64].

Solubility and molecular weight of mushroom glucan: The solubility of β-glucans in water is dependent on structures of their side chain which are specific to individual fungi species [65]. In fungi, β-glucans are present either in their water-soluble or insoluble form. It is known that the solubility of β-glucan increases with temperature. The (1→3)-β-D-glucans are completely insoluble in water with a high degree of polymerization (DP > 100) [66] due to stronger interactions and associations between chains than between the chains and water molecules. Solubility increases as the degree of polymerization decreases.

The β-glucans, isolated from *Ganoderma lucidum*, is a biological response modifier (BRM), but a major difficulty to the clinical utilization of this glucan is their relative lack of solubility in water. Water insoluble fungal glucans by alkali from the mycelia of *Ganoderma lucidum* were sulfated to yield their corresponding water-soluble derivatives. Soluble β-glucans show stronger immune-stimulators than insoluble β-glucans. A water insoluble (1→3)-β-glucan (*m.w.*: 9.16×10^4 Da) from *Pleurotus djamor* was solubilized with 4% NaOH followed by neutralization [27] with HCl and possesses *in vitro* anticancer property against ovarian carcinoma PA1 cells. The average levels of β-glucans in different mushrooms [25] are given in Table-3.

TABLE-3
AVERAGE β-GLUCAN CONTENT AND THEIR WATER-SOLUBLE AND WATER-INSOLUBLE FRACTIONS (%) FROM DIFFERENT MUSHROOM [Ref. 25]

Name of fungus	Content of β-glucans (mg/100 g dry wt.)	Water-soluble β-glucan (%)	Water-insoluble β-glucan (%)
Pleurotus ostreatus	38	37.8	62.2
Pleurotus eryngii	38	16.8	83.2
Pleurotus pulmonarius	53	18.7	81.3
Lentinus edodes	22	46.1	53.9

The two water insoluble protein containing (1→3)-β-D-glucans showed antitumor-activity and they were composed of glucan and protein with the ratio of 80:20 and 68:32 (w/w), respectively and their molecular weights were observed as 68×10^4 Da and 40×10^4 Da. And another two water insoluble β-D-glucans having comparatively higher molecular weights 190×10^4 Da and 120×10^4 Da, respectively were comprise of glucan and protein (87:13, w/w) [67].

Degree of branching, conformation and chain rigidity of glucan: A variety of β-glucans differing in structures has been isolated from various sources. The differences are in primary structure (degree of branching (DB), degree of polymerization (DP) and linkage type) and conformation *e.g.* triple helix, single helix and random coil structure [68-72]. The highest degree of biological activity of glucan was observed at branching degrees ranging from 0.20 to 0.33 [66] (Table-4).

The conformation of some linear and branched β-D-glucans have been studied and such linear and branched (1→3)-β-D-glucans, *e.g.* curdlan (isolated from *Acalgenes faecalis*) [72], schizophyllan (isolated from *Schizophyllum commune*) [68,69] and T-N-5 (isolated from *Dictyophora indusiata* FISCH) [71] have been reported to have triple helical structure from the results

TABLE-4
DEGREE OF BRANCHING (DB) OF DIFFERENT β-GLUCANS

Name of fungus	β-Glucans	Degree of branching (DB)
Poria cocas	Pachymaran	0.015-0.02
Pleurotus ostreatus	Pleuran	0.25
Sclerotium glucanicum	Scleroglucan	0,30
Grifola frondosa	Grifolan	0.31-0.36
Lentinus edodes	Lentinan	0.23-.033
Schizophyllum commune	Schizophyllan	0.33

of X-ray diffraction analysis, viscosity and other studies [73, 74]. Small-angle X-ray scattering experiment as performed by Gawronski *et al*. [75] was established the triple helical structure of β-glucan in solution also.

Using laser light scatterings (LLS) and small angle neutron scattering (SANS), Rees *et al*. [76-78] replicated linear and branched pyranosic glucans on the basis of molecular parameters and also simplified the conformations of glucan with various glycosidic linkages (Table-5).

TABLE-5
CONFORMATIONS OF GLUCANS WITH VARIOUS GLYCOSIDIC LINKAGES

Glucans (linkages)	Conformations
α-(1→2)-D-glucan	Rigid and crumpled
α-(1→3)-D-glucan	Extended and ribbon-like
α-(1→4)-D-glucan	Flexible and helical
β-(1→2)-D-glucan	Rigid and crumpled
β-(1→3)-D-glucan	Flexible and helical
β-(1→4)-D-glucan	Extended and ribbon-like
β-(1→6)-D-glucan	Flexible

The (1→6)-α- and (1→6)-β-glucans have many possible conformations than glucans in other linkages due to freedom in rotation is much higher as residues separated by three bonds rather than two than that of other linkages. Therefore, it shows typical flexibility. In 1983, Burton and Brant [79] calculated an energy function for conformational analysis of glucans with different linkages. They introduced molecular parameters including configuration entropy (ΔS_c), characteristic ratio (C_∞) and persistence length (q) to explain chain rigidity. As q value increases chain rigidity increases. From the calculated q value, the order of chain rigidity of glucans is as follows: (1→4)-β- > (1→3)-β- > (1→4)-β- > (1→3)-β- > (1→6)-β- > (1→6)-β-. This explanation is consistent with the observation of Rees *et al*. [76-78].

Different biological activities of glucans

Immuno stimulating and antitumor effects: Biologically active polysaccharides are defined as biological response modifiers (BRMs), which have been defined as those agents that stimulate the host's biological immune system and result in various therapeutic effects. The main criteria for BRMs are (i) source harmless and address no additional stress on the body, (ii) the body must adjust to various environmental and biological pressures, (iii) use a generic action on the body, associate some or all of the major systems, including nervous, hormonal and immune systems, as well as regulatory functions [80].

These biopolymers are known to be active against tumor cells, viral and bacterial infections, inflammations and also to provoke an increased synthesis of hormones and cells of the host immune system. Glucans exhibit their ability to lower cholesterol and blood sugar levels, acting as non-digestible dietary fibers, act as anti oxidants and free radical scavengers, as well as hepato protective molecules [67].

These properties of glucans greatly depend on their structural and physico-chemical characteristics. The molecular weight of β-glucans is one of the factors affecting their ability to interact with the surface of leukocyte [81] with a higher molecular weight being more advantageous [67].

During the course of immune system stimulation, the most positive effect was obtained with (1→3)-β-glucan. The biological activity is based on its interaction with specific β-glucopyranose receptors present on leukocytes [82]. This interaction depends not only by the conformation of the glucan molecule but also by the degree of its water solubility, water-soluble glucans show much better efficiency [81].

The isolation process for these polysaccharides (water or alkali extraction from fruit bodies, alcohol precipitation of polysaccharides) has an important role on their size, composition and functionality. In human body, the effects of β-glucans are dependent on the pH at which they interact with leukocytes. In alkali medium, the structure of a triple glucan helix is split and simple helices are formed. When the glucan solution is neutralized, it increases the share of molecules with a single helix that can show a high ability to attach themselves to some proteins and to form complexes. Then it stimulate production of antibodies by macrophages [83]. In an acidic medium, the biological efficiency of β-glucans is reduced due to disruption of hydroxylic groups occurring on the surface of chains. The activity may also reduce due to presence of epoxy group [83]. The biological action of Lentinan has been demonstrated by Chihara *et al*. [84] and possible mode of action of β-D-glucan as biological response modifier (BRM) was established by Mizuno *et al*. [85]. β-Glucan from maitake mushroom can inhibit the hormone-refractory prostate cancer [86].

Hong *et al*. [87] reported that the oral uptake of β-glucans labelled with fluorescein were taken up by macrophages *via* the Dectin-1 receptor and the macrophages degraded the large β-1,3-glucans into smaller soluble β-1,3-glucan fragments that were subsequently taken up *via* the complement receptor 3 (CR3) of granulocytes and the CR3-bound β-glucan-fluorescein were shown to kill tumor cells coated with monoclonal antibody [88] (Fig. 1).

Antibacterial activity: β-glucans of highly branched (1→3)- and (1→6)-linkages from mushroom *Lentinula edodes* show anti microbial activity *in vitro* against Gram positive and Gram negative bacteria, such as *Bacillus megraterium* NCIB 2602, *Enterococcus phoeniculicola* JLB-IT and *Kiebsiella peneumoniae* K4 [49]. The β-(1→3)-glucans from mushroom *Schizophyllum commune* and *Sclerotium glucanicum* competent to enhance protection against bacterial infection in yellowtail through the non-specific immune system activation was identified by Matsuyama *et al*. [89]. β-Glucans from *Pleurotus ostreatus* protect athletes against infections of respiratory tract [90]. The

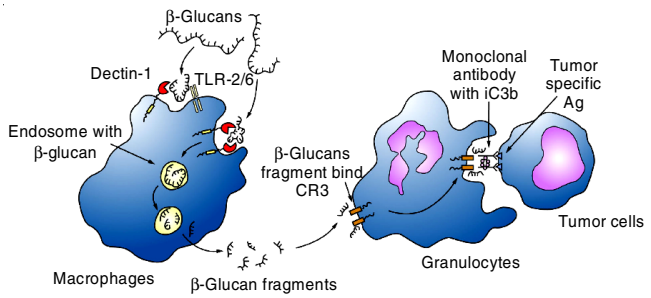

Fig. 1. Mode of action of β-glucan on tumor cells at molecular level [Ref. 88]

polysaccharide isolated from *Lentinus edodes* extract exhibited antimicrobial properties against oral bacterial pathogens [91].

In recent year, the glucans are used to prepare Ag/Au nanoparticles conjugated glucan which are effective against antibiotic resistance bacteria. Silver nanoparticles prepared by glucans isolated from *Pleurotus florida* blue variant mushrooms inhibited the multiple antibiotic-resistant (MAR) bacterium *Klebsiella pneumoniae* [22].

Antiviral activity: Native and chemically modified mushroom polysaccharides exhibit antiviral activities against pathogenic viruses. Polysaccharide from the mushrooms *Pleurotus abalones* inhibited the HIV virus [92]. The non-sulphated and sulphated polysaccharides completely inhibited cell to cell infection of HIV-1 and HIV-2 and a human T-cell lymphotropic virus type 1 (HTLV-1). The native and sulphated derivative of polysaccharide from *Agaricus brasiliensis* [93] showed strong anti-herpes simplex virus activities [94,95]. A water insoluble β-1,3/1,6-D-glucan, isolated from pleuran (*Pleurotus ostreatus*) showed antiviral activity [96] against herpes simplex virus type 1 (HSV-1) also. The polysaccharide isolated from *Lentinula edodes* mushrooms exhibited antiviral activity against the bovine herpes simplex type I and poliovirus type I viruses [97]. A mushroom lentinan and its sulphated derivative inhibited tobacco seedlings against viral infection by the tobacco mosaic virus [98].

Conclusion

Glucans are potent immunomodulator that have multiple activities such as antitumor, antibacterial and antiviral activities. Mushroom polysaccharides are of different chemical composition, mainly belonging to the group of (1→3)-, (1→6)-β-glucans and (1→3), (1→6)- branched β-glucans. The more bioactivity was found in the β-glucans having (1→3) linkages. The isolation processes for these polysaccharides an important role on their size, composition, functionality and solubility. β-Glucans with higher molecular weight have more advantage to interact with the surface of leukocyte. The highest degree of biological activity of glucan was observed at branching degrees ranging from 0.20 to 0.33. In human body, the effects of β-glucans are dependent on the pH at which they interact with leukocytes. The recent trends in nano-biotechnology give emphasis on the use of biological entities instead of chemical reagents for synthesis of nanoparticles. Hence, the use of bioactive glucans for nanoparticle synthesis gives a new direction for medical sciences.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

REFERENCES

1. J.L. Mau, C.C. Chyau, J.Y. Li and Y.H. Tseng, *J. Agric. Food Chem.*, **45**, 4726 (1997); https://doi.org/10.1021/jf9703314
2. P. Oei, Mushroom Cultivation, Appropriate Technology for Mushroom Growers: Backhugs Publishers: Leiden, The Netherlands (2003).
3. S.P. Wasser and L.A. Weis, *Int. J. Med. Mushrooms*, **1**, 31 (1999); https://doi.org/10.1615/IntJMedMushrooms.v1.i1.30
4. W.M. Breene, *J. Food Prot.*, **53**, 883 (2010); https://doi.org/10.4315/0362-028X-53.10.883
5. P. Manzi, A. Aguzzi and L. Pizzoferrato, *Food Chem.*, **73**, 321 (2001); https://doi.org/10.1016/S0308-8146(00)00304-6
6. T.K. Ajith and K. Janardhanan, *J. Clin. Biochem. Nutr.*, **40**, 157 (2007); https://doi.org/10.3164/jcbn.40.157
7. J.C. Santos-Neves, M.I. Pereira, E.R. Carbonero, A.H. Gracher, P.A. Gorin, G.L. Sassaki and M. Iacomini, *Carbohydr. Res.*, **343**, 1456 (2008); https://doi.org/10.1016/j.carres.2008.03.001
8. V.C. Ooi and F. Liu, *Curr. Med. Chem.*, **7**, 715 (2000); https://doi.org/10.2174/0929867003374705
9. T. Kiho, Y. Shiose, K. Nagai, M. Sakushima and S. Ukai, *Chem. Pharm. Bull. (Tokyo)*, **40**, 2212 (1992); https://doi.org/10.1248/cpb.40.2212
10. I. Yoshida, T. Kiho, S. Usui, M. Sakushima and S. Ukai, *Biol. Pharm. Bull.*, **19**, 114 (1996); https://doi.org/10.1248/bpb.19.114
11. A. Misaki and M. Kakuta, *Food Rev. Int.*, **11**, 211 (1995); https://doi.org/10.1080/87559129509541035
12. N. Ohno, K. Saito, J. Nemoto, S. Kaneko, Y. Adachi, M. Nishijima, T. Miyazaki and T. Yadomae, *Biol. Pharm. Bull.*, **16**, 414 (1993); https://doi.org/10.1248/bpb.16.414
13. E.S. Olafsdottir, K. Ingolfsdottir, H. Barsett, B. Smestad Paulsen, K. Jurcic and H. Wagner, *Phytomedicine*, **6**, 33 (1999); https://doi.org/10.1016/S0944-7113(99)80032-4
14. T. Mizuno, R. Inagaki, T. Kanao, T. Hagiwara, T. Nakamura, H. Ito, K. Shimura, T. Sumiya and A. Asakura, *Agric. Biol. Chem.*, **54**, 2897 (1990); https://doi.org/10.1271/bbb1961.54.2897
15. S.K. Bhanja, C.K. Nandan, S. Mandal, B. Bhunia, T.K. Maiti, S. Mondal and S.S. Islam, *Carbohydr. Res.*, **357**, 83 (2012); https://doi.org/10.1016/j.carres.2012.04.007
16. F.R. Smiderle, L.M. Olsen, E.R. Carbonero, C.H. Baggio, C.S. Freitas, R. Marcon, A.R. Santos, P.A.J. Gorin and M. Iacomini, *Eur. J. Pharmacol.*, **597**, 86 (2008); https://doi.org/10.1016/j.ejphar.2008.08.028
17. F.R. Smiderle, G. Alquini, M.Z. Tadra-Sfeir, M. Iacomini, H.J. Wichers and L.J.L.D. Van Griensven, *Carbohydr. Polym.*, **94**, 91 (2013); https://doi.org/10.1016/j.carbpol.2012.12.073
18. H. Kawagishi, T. Kanao, R. Inagaki, T. Mizuno, K. Shimura, H. Ito, T. Hagiwara and T. Nakamura, *Carbohydr. Polym.*, **12**, 393 (1990); https://doi.org/10.1016/0144-8617(90)90089-B
19. T. Mizuno, H. Saito, T. Nishitoba and H. KaWagishi, *Food Rev. Int.*, **11**, 23 (1995); https://doi.org/10.1080/87559129509541018
20. K. Sakurai, K. Uezu, M. Numata, T. Hasegawa, C. Li, K. Kaneko and S. Shinkai, *Chem. Commun.*, 4383 (2005); https://doi.org/10.1039/b506673p

21. I.K. Sen, K. Maity and S.S. Islam, *Carbohydr. Polym.*, **91**, 518 (2013); https://doi.org/10.1016/j.carbpol.2012.08.058
22. I.K. Sen, A.K. Mandal, S. Chakraborti, B. Dey, R. Chakraborty and S.S. Islam, *Int. J. Biol. Macromol.*, **62**, 439 (2013); https://doi.org/10.1016/j.ijbiomac.2013.09.019
23. C.H. Grun, Ph.D. Dissertation, Structure and Biosynthesis of Fungal α-Glucans, Faculteit Scheikunde, Universiteit Utrecht, Netherlands (2003).
24. D.J. Bell and D.H. Northcote, *J. Chem. Soc.*, 1944 (1950); https://doi.org/10.1039/jr9500001944
25. P. Manzi and L. Pizzoferrato, *Food Chem.*, **68**, 315 (2000); https://doi.org/10.1016/S0308-8146(99)00197-1
26. K. Tabata, W. Ito, T. Kojima, S. Kawabata and A. Misaki, *Carbohydr. Res.*, **89**, 121 (1981); https://doi.org/10.1016/S0008-6215(00)85234-9
27. G.N. Maity, P. Maity, I. Choudhuri, N. Bhattacharyya, K. Acharya, S. Dalai and S. Mondal, *Carbohydr. Polym.*, **222**, 114990 (2019); https://doi.org/10.1016/j.carbpol.2019.114990
28. H. Abreu, F.F. Simas, F.R. Smiderle, V. Sovrani, J.L. Dallazen, D. Maria-Ferreira, M.F. Werner, L.M.C. Cordeiro and M. Iacomini, *Int. J. Biol. Macromol.*, **122**, 1128 (2019); https://doi.org/10.1016/j.ijbiomac.2018.09.062
29. L.I. de Jesus, F.R. Smiderle, L.M.C. Cordeiro, R.A. de Freitas, L.J.L.D. VanGriensven and M. Iacomini, *Carbohydr. Polym.*, **200**, 353 (2018); https://doi.org/10.1016/j.carbpol.2018.08.004
30. P. Maity, A.K. Nandi, D.K. Manna, M. Pattanayak, I.K. Sen, S.K. Bhanja, S. Samanta, B.C. Panda, S. Paloi, K. Acharya and S.S. Islam, *Carbohydr. Polym.*, **157**, 1237 (2017); https://doi.org/10.1016/j.carbpol.2016.11.006
31. P. Maity, I.K. Sen, P.K. Maji, S. Paloi, K.S.P. Devi, K. Acharya, T.K. Maiti and S.S. Islam, *Carbohydr. Polym.*, **123**, 350 (2015); https://doi.org/10.1016/j.carbpol.2015.01.051
32. Y. Zhang, Q. Li, Y.M. Shu, H.J. Wang, Z.M. Zheng, J.L. Wang and K.P. Wang, *J. Funct. Foods*, **15**, 151 (2015); https://doi.org/10.1016/j.jff.2015.03.025
33. A.K. Nandi, S. Samanta, S. Maity, I.K. Sen, S. Khatua, K.S.P. Devi, K. Acharya, T.K. Maiti and S.S. Islam, *Carbohydr. Polym.*, **99**, 774 (2014); https://doi.org/10.1016/j.carbpol.2013.09.016
34. P. Maity, S. Samanta, A.K. Nandi, I.K. Sen, S. Paloi, K. Acharya and S.S. Islam, *Int. J. Biol. Macromol.*, **63**, 140 (2014); https://doi.org/10.1016/j.ijbiomac.2013.10.040
35. C.I. Lee, C.C. Wu, S.L. Hsieh, C.L. Lee, Y.P. Chang, C.C. Chang, Y.Z. Wang and J.J. Wang, *Food Funct.*, **5**, 3224 (2014); https://doi.org/10.1039/C4FO00720D
36. S. Samanta, K. Maity, A.K. Nandi, I.K. Sen, K.S.P. Devi, S. Mukherjee, T.K. Maiti, K. Acharya and S.S. Islam, *Carbohydr. Res.*, **367**, 33 (2013); https://doi.org/10.1016/j.carres.2012.12.002
37. C. Deng, H. Fu, L. Teng, Z. Hu, X. Xu, J. Chen and T. Ren, *Int. J. Biol. Macromol.*, **61**, 453 (2013); https://doi.org/10.1016/j.ijbiomac.2013.08.007
38. S.K. Bhanja, D. Rout, P. Patra, C.K. Nandan, B. Behera, T.K. Maiti and S.S. Islam, *Carbohydr. Res.*, **374**, 59 (2013); https://doi.org/10.1016/j.carres.2013.03.023
39. S. Samanta, A.K. Nandi, I.K. Sen, P.K. Maji, K.S.P. Devi, T.K. Maiti and S.S. Islam, *Int. J. Biol. Macromol.*, **61**, 89 (2013); https://doi.org/10.1016/j.ijbiomac.2013.06.010
40. S.C. Kang, H.J. Koo, S. Park, J.D. Lim, Y.J. Kim, T. Kim, S. Namkoong, K.-H. Jang, S. Pyo, S.-A. Jang and E.-H. Sohn, *Int. J. Biol. Macromol.*, **57**, 9 (2013); https://doi.org/10.1016/j.ijbiomac.2013.03.017
41. E.K. Mandal, K. Maity, S. Maity, S.K. Gantait, B.T. Behera, K. Maiti, S.R. Sikdar and S.S. Islam, *Carbohydr. Res.*, **347**, 172 (2012); https://doi.org/10.1016/j.carres.2011.10.040
42. A.K. Nandi, I.K. Sen, S. Samanta, K. Maity, K.S.P. Devi, S. Mukherjee, T.K. Maiti, K. Acharya and S.S. Islam, *Carbohydr. Res.*, **363**, 43 (2012); https://doi.org/10.1016/j.carres.2012.10.002
43. X. Xu, P. Chen, L. Zhang and H. Ashida, *Carbohydr. Polym.*, **87**, 1855 (2012); https://doi.org/10.1016/j.carbpol.2011.10.015
44. Q. Dong, Y. Wang, L. Shi, J. Yao, J. Li, F. Ma and K. Ding, *Carbohydr. Res.*, **353**, 100 (2012); https://doi.org/10.1016/j.carres.2012.02.029
45. Y. Masuda, T. Togo, S. Mizuno, M. Konishi and H. Nanba, *J. Leukoc. Biol.*, **91**, 547 (2012); https://doi.org/10.1189/jlb.0711386
46. E.R. Carbonero, A.C. Ruthes, C.S. Freitas, P. Utrilla, J. Gálvez, E.V. Silva, G.L. Sassaki, P.A.J. Gorin and M. Iacomini, *Carbohydr. Polym.*, **90**, 814 (2012); https://doi.org/10.1016/j.carbpol.2012.06.005
47. A. Klaus, M. Kozarski, M. Niksic, D. Jakovljevic, N. Todorovic and L.J.L.D. Van Griensven, *LWT-Dood Sci. Technol.*, **44**, 2005 (2011); https://doi.org/10.1016/j.lwt.2011.05.010
48. S.K. Bhunia, B. Dey, K.K. Maity, S. Patra, S. Mandal, S. Maiti, T.K. Maiti, S.R. Sikdar and S.S. Islam, *Carbohydr. Res.*, **346**, 2039 (2011); https://doi.org/10.1016/j.carres.2011.05.029
49. G.E. Rasmy, W.A. Botros, S. Kabeil and A.S. Daba, *Aust. J. Basic Appl. Sci.*, **4**, 1118 (2010).
50. S.K. Roy, D. Das, S. Mondal, D. Maiti, B. Bhunia, T.K. Maiti and S.S. Islam, *Carbohydr. Res.*, **344**, 2596 (2009); https://doi.org/10.1016/j.carres.2009.09.010
51. X. Luo, X.Y. Xu, M.Y. Yu, Z.R. Yang and L.Y. Zheng, *Food Chem.*, **111**, 357 (2008); https://doi.org/10.1016/j.foodchem.2008.03.076
52. C.M. Camelini, M. Maraschin, M.M. de Mendonça, C. Zucco, A.G. Ferreira and L.A. Tavares, *Biotechnol. Lett.*, **27**, 1295 (2005); https://doi.org/10.1007/s10529-005-0222-6
53. Y. Wang, L. Zhang, Y. Li, X. Hou and F. Zeng, *Carbohydr. Res.*, **339**, 2567 (2004); https://doi.org/10.1016/j.carres.2004.08.003
54. P. Mallick and S.R. Sikdar, *World J. Microbiol. Biotechnol.*, **30**, 2283 (2014); https://doi.org/10.1007/s11274-014-1652-x
55. P. Mallik and S.R. Sikdar, *Int. J. Pharma Bio Sci.*, **6**, 301 (2015).
56. U. Chakraborty and S.R. Sikdar, *World J. Microbiol. Biotechnol.*, **26**, 213 (2010); https://doi.org/10.1007/s11274-009-0162-8
57. U. Chakraborty and S.R. Sikdar, *World J. Microbiol. Biotechnol.*, **24**, 1481 (2008); https://doi.org/10.1007/s11274-007-9630-1
58. P.K. Maji, I.K. Sen, K.S.P. Devi, T.K. Maiti, S.R. Sikdar and S.S. Islam, *Bioact. Carbohydr. Diet. Fibre*, **2**, 73 (2013); https://doi.org/10.1016/j.bcdf.2013.09.002
59. I.K. Sen, P.K. Maji, B. Behera, T.K. Maiti, P. Mallick, S.R. Sikdar and S.S. Islam, *Int. J. Biol. Macromol.*, **53**, 127 (2013); https://doi.org/10.1016/j.ijbiomac.2012.11.014
60. K.K. Maity, S. Patra, B. Dey, S.K. Bhunia, S. Mandal, B. Bahera, T.K. Maiti, S.R. Sikdar and S.S. Islam, *Carbohydr. Res.*, **370**, 13 (2013); https://doi.org/10.1016/j.carres.2013.01.016
61. P.K. Maji, I.K. Sen, B. Behera, T.K. Maiti, P. Mallick, S.R. Sikdar and S.S. Islam, *Carbohydr. Res.*, **358**, 110 (2012); https://doi.org/10.1016/j.carres.2012.06.017
62. R. Sarkar, C.K. Nandan, S.K. Bhunia, S. Maiti, T.K. Maiti, S.R. Sikdar and S.S. Islam, *Carbohydr. Res.*, **347**, 107 (2012); https://doi.org/10.1016/j.carres.2011.10.043
63. K. Maity, E. Kar (Mandal), S. Maity, S.K. Gantait, D. Das, S. Maiti, T.K. Maiti, S.R. Sikdar and S.S. Islam, *Int. J. Biol. Macromol.*, **49**, 555 (2011); https://doi.org/10.1016/j.ijbiomac.2011.06.007
64. D. Das, S. Mondal, S.K. Roy, D. Maiti, B. Bhunia, T.K. Maiti, S.R. Sikdar and S.S. Islam, *Carbohydr. Res.*, **345**, 974 (2010); https://doi.org/10.1016/j.carres.2010.02.028
65. O. Rop, J. Mlcek and T. Jurikova, *Nutr. Rev.*, **67**, 624 (2009); https://doi.org/10.1111/j.1753-4887.2009.00230.x
66. J.A. Bohn and J.N. BeMiller, *Carbohydr. Polym.*, **28**, 3 (1995); https://doi.org/10.1016/0144-8617(95)00076-3
67. S.P. Wasser, *Appl. Microbiol. Biotechnol.*, **60**, 258 (2002); https://doi.org/10.1007/s00253-002-1076-7
68. S.T. Kikumoto, T. Miyajina, S. Yoshijumi, S. Fujimoto and K. Kimura, *Nippon Nogei Kagaku Kaishi (Jpn. J. Agric. Chem.),* **44**, 337 (1970).
69. T. Komura, H. Nagayama and S. Wada, *Nippon Nogei Kagaku Kaishi (Jpn. J. Agric. Chem.)*, **45**, 337 (1971); https://doi.org/10.1271/nogeikagaku1924.45.337
70. Y. Yoshioka, R. Tabeta, H. Saitô, N. Uehara and F. Fukuoka, *Carbohydr. Res.*, **140**, 93 (1985); https://doi.org/10.1016/0008-6215(85)85052-7

71. C. Hara, T. Kiho, Y. Tanaka and S. Ukai, *Carbohydr. Res.*, **110**, 77 (1982); https://doi.org/10.1016/0008-6215(82)85027-1
72. T. Harada, A. Misaki and H. Saito, *Arch. Biochem. Biophys.*, **124**, 292 (1968); https://doi.org/10.1016/0003-9861(68)90330-5
73. R.H. Marchessault, K. Deslandes, K. Ogawa and P.R. Sundararajan, *Can. J. Chem.*, **55**, 300 (1977); https://doi.org/10.1139/v77-045
74. T. Norisuye, T. Yanaki and H. Fujita, *J. Polym. Sci*., *Polym. Phys. Ed.*, **18**, 547 (1980); https://doi.org/10.1002/pol.1980.180180314
75. M. Gawronski, J.T. Park, A.S. Magee and H. Conrad, *Biopolymers*, **50**, 569 (1999); https://doi.org/10.1002/(SICI)1097-0282(199911)50:6<569::AID-BIP1>3.0.CO;2-B
76. D.A. Rees, *J. Chem. Soc. B*, 217 (1969); https://doi.org/10.1039/J29690000217
77. D.A. Rees and W.E. Scott, *J. Chem. Soc. Chem. Commun.*, 1037 (1969); https://doi.org/10.1039/C29690001037
78. D.A. Rees and W.E. Scott, *J. Chem. Soc. B*, **3**, 469 (1971); https://doi.org/10.1039/j29710000469
79. B.A. Burton and D.A. Brant, *Biopolymers*, **22**, 1769 (1983); https://doi.org/10.1002/bip.360220712
80. Brekhman II, Man and Biologically Active Substances, Pergamon Press: New York, USA (1980).
81. M. Mizuno and Y. Nishitani, *J. Clin. Biochem. Nutr.*, **52**, 202 (2013); https://doi.org/10.3164/jcbn.13-3
82. T. Yadomae, *Yakugaku Zasshi*, **120**, 413 (2000); https://doi.org/10.1248/yakushi1947.120.5_413
83. Y. Adachi, N.N. Miura, N. Ohno, H. Tamura, S. Tanaka and T. Yadomae, *Carbohydr. Polym.*, **39**, 225 (1999); https://doi.org/10.1016/S0144-8617(99)00014-4
84. G. Chihara, J. Hamuro, Y.Y. Maeda, T. Shiio, T. Suga, N. Takasuka and T. Sasaki, *Cancer Detect. Prev*., **Suppl.1**, 423 (1987).
85. T. Mizuno, *Int. J. Med. Mushrooms*, **4**, 14 (2002); https://doi.org/10.1615/IntJMedMushr.v4.i4.30
86. S.A. Fullerton, A.A. Samadi, D.G. Tortorelis, M.S. Choudhury, C. Mallouh, H. Tazaki and S. Konno, *Mol. Urol.*, **4**, 7 (2000).
87. F. Hong, J. Yan, J.T. Baran, D.J. Allendorf, R.D. Hansen, G.R. Ostroff, P.X. Xing, N.K. Cheung and G.D. Ross, *J. Immunol.*, **173**, 797 (2004); https://doi.org/10.4049/jimmunol.173.2.797
88. G. Chi-Fung Chan, W. Keung Chan and D. Man-Yuen Sze, *J. Hematol. Oncol.*, (2009).
89. H. Matsuyama, R.E.P. Mangindaan and T. Yano, *Aquaculture*, **101**, 197 (1992); https://doi.org/10.1016/0044-8486(92)90023-E
90. K. Bergendiova, E. Tibenska and J. Majtan, *Eur. J. Appl. Physiol.*, **111**, 2033 (2011); https://doi.org/10.1007/s00421-011-1837-z
91. C. Signoretto, A. Marchi, A. Bertoncelli, G. Burlacchini, A. Papetti, C. Pruzzo, E. Zaura, P. Lingstrom, I. Ofek, J. Pratten, D.A. Spratt, M. Wilson and P. Canepari, *BMC Complement. Altern. Med.*, **14**, 75 (2014); https://doi.org/10.1186/1472-6882-14-75
92. C.R. Wang, T.B. Ng, L. Li, J.C. Fang, Y. Jiang, T.Y. Wen, W.T. Qiao, N. Li and F. Liu, *J. Pharm. Pharmacol.*, **63**, 825 (2011); https://doi.org/10.1111/j.2042-7158.2011.01274.x
93. M.C. Minari, V.P. Rincao, S.A. Soares, N.M.P.S. Ricardo, C. Nozawa and R.E.C. Linhares, *Acta Virol.*, **55**, 255 (2011); https://doi.org/10.4149/av_2011_03_255
94. F.T. Cardozo, C.M. Camelini, P.C. Leal, J.M. Kratz, R.J. Nunes, M.M. Mendonca and C.M. Simoes, *Intervirology*, **57**, 375 (2014); https://doi.org/10.1159/000365194
95. K.A. Yamamoto, I.C.F. Galhardi, V.P. Rincao, S.D.A. Soares, T.G.P. Vieira, N.M.P.S. Ricardo, C. Nozawa and R.E.C. Linhares, *Int. J. Biol. Macromol.*, **52**, 9 (2013); https://doi.org/10.1016/j.ijbiomac.2012.09.029
96. I. Urbancikova, D. Hudackova, J. Majtan, Z. Rennerova, P. Banovcin and M. Jesenak, *Evid. Based Complement Alternat. Med.*, **2020**, 8562309 (2020); https://doi.org/10.1155/2020/8562309
97. V.P. Rincao, K.A. Yamamoto, N.M. Ricardo, S.A. Soares, L.D. Meirelles, C. Nozawa and R.E. Linhares, *Virol. J.*, **9**, 37 (2012); https://doi.org/10.1186/1743-422X-9-37
98. J. Wang, G. Yu, Y. Li, L. Shen, Y. Qian, J. Yang and F. Wang, *Pestic. Biochem. Physiol.*, **122**, 38 (2015); https://doi.org/10.1016/j.pestbp.2014.12.027