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A Review on Edible Straw Mushrooms: A Source of High Nutritional Supplement, Biologically Active Diverse Structural Polysaccharides

Kaushik Ghosh*

Department of Chemistry, Ghatal Rabindra Satabarsiki Mahavidyalaya, Paschim Medinipur-721212, West Bengal, India.
kghoshgrsm@rediffmail.com

Abstract: **Mushrooms have been used as nutritious healthy foods throughout the world. In modern medicine, mushrooms represent an importantsource that has high proportion of polysaccharides showing considerable antitumor and immunomodulating properties. These polysaccharides are mostly glucans with different glycosidic linkages, such as (1→3),(1→6)-β-glucan, (1→3)-α-glucans, and some heteroglycans.These are also used as food additives and dietary supplements. Some of the commonly available edible mushrooms of the genus *Volvariella*, namely *Volvariella diplasia,Volvariella bombycina and Volvariella volvacea* are commonly known as straw mushroom. These possess excellent nutritional value with more protein than any other vegetables. A diversity of structures has been proposed for several polysaccharides isolated from different straw mushrooms in different extraction medium. They exhibit different medicinal properties. This paper reviews the structural elucidation, nutritional composition and bioactivity of these polysaccharides and recycling of agricultural wastes and environmental potential of these mushrooms.**

Keywords: **Medicinal properties, Nutritional composition, Polysaccharides, Straw mushrooms, *Volvariella*.**

I. INTRODUCTION

Changes of global climate have a high impact on the traditional cereal based food resources due to increase in temperature and carbon-di-oxide concentration, lack of water and cultivable land and low productivity. Developing countries like India with its high population has to handle the very basic problem of inadequate food supplies, decreasing quality of health and balancing the ecosystem under the changing of climate. Fungi and bacteria have better ability to adapt the changed environmental conditions as compared to green plants. This is the advantages of cultivating mushrooms as an alternative crop. Among fungi currently cultivated worldwide, *Volvariella* spp, occurs in both tropical and subtropical regions, ideal for growing in rural areas as they require a relatively low cost. *V. diplasia* is generally available in the market during the months of June-July when the temperature remains around 30-35ºC. However, unlike *V. volvacea*, its cultivation is facilitated at somewhat lower temperature (26-30ºC) (Ahlawat&Singh, 2016).*V.diplasia* is white straw mushroom whereas *V. bombycina*exists as yellow fruit bodies with silky appearance, and hence commonly called as silver silk straw mushroom (Ahlawat&Singh, 2016). These are considered as quite favourite food item for the local people.

Mushroom polysaccharides are source of physiologically beneficial and nontoxic medicines (Wasser& Weis, 1999).These polysaccharides showed immunomodulatory and anti-cancer activity (Moradali&Hedjaroude, 2007). Edible mushrooms,*V. volvacea, V. diplasia and V. bombycina* belonging to the *Pluteaceac* family have high nutritive value. Polysaccharides of these straw mushrooms exhibit different biological activities(Cheung,1996;Kishida&Misaki,1989;Ooi,2001;Chiu&Pang,1995;Mohanty&Chaudhury,2002;Sze&Liu,2004;Chiu&Chang,1995).

Owing to its unique ability to decompose agricultural waste, *Volvariella spp.* can play an important role in waste management and in the control of air pollution as well (Pinedo-Rivilla&Collado, 2009). It can absorb toxins directly into their tissues especially heavy metals (Prakash,2017;Ali &Sajad,2013; Dey&Bandyopadhyay,1995).The present review analyses the

*Corresponding Author

nutritional composition, structural features and medicinal properties of different polysaccharides of straw mushrooms.

II. NUTRITIONAL COMPOSITION

Mushroomsare important sources of carbohydrates, fiber, mineralsand proteins, (Senatore, 1990; Adewusi&Oke, 1993) where the amino acids are comparable to animal proteins (Aletor, 1995).Proteins in mushrooms find its position in between animal proteins and vegetable proteins (Kurtzman, 1976; Purkayastha&Nayak, 1981). Water is the main component of Mushrooms (~90%). The remaining parts containprotein (10-40%), fat (2-8%), carbohydrate (3-28%), fiber(3-32%), ash (8-10%) and minerals likecalcium, magnesium, iron, potassium, phosphorous,copper, zinc etc.(Breene,1990).Edible mushrooms contain different bioactive molecules including nucleotides, terpenoids, glycoproteins and polysaccharides. Ergosterol, (Huang&Chang, 1985) provitaminD2 is also present in mushroom. Nutritional composition (Lee & Chang, 1975; Chang &Hayes, 2013; Jagadeesh &Ayyappan, 2010) of different straw mushrooms is given in Table 1.

Table 1. Nutritional composition of edible straw mushrooms shown in percentage

Parameter	*V. volvacea* (Lee& Chang,1975)	*V. diplasia* (Chang & Hayes,2013)	*V. bombycina* (Jagadeesh& Ayyappan,2010)
Carbohydrate	50.90	57.40	38.90
Protein	30.10	28.50	28.30
Lipid/Fats	6.40	2.60	2.72
Ash	12.60	11.50	10.90
Fiber	11.90	17.40	24.60

These mushrooms possess all nine aminoacids (leucine, lysine, tryptophane, methionine, threonine, histidine, valine, Isoleucine, and phenylalanine) which are essential to make the proteins that operate different functions of our bodies (Chang& Miles,1989;Cheung,2008;Bano&Singh,1971;FAO/WHO,1990; Kurtzman,2005)(Table 2).These amino acids are comparable to that of egg proteins. For all three mushrooms, lysine is most abundant EAA (essential amino acids) whereas the quantity of tryptophane and methionine are at the lowest level. *V. bombycine* contains cysteine and tyrosine also.

Mushrooms proteins, being rich in lysine, can be considered as an ideal food for supplementing lysine deficient cereal based diets (Sohi, 1990).

The mushrooms contain crude fats, having all types of lipid compounds such as monoglycerides, diglycerides, triglycerides, sterol esters, phospholipids, sterols and free fatty acids.On account of possessing high amount of provitaminD2 and ergosterol, *V.Volvacea* contains low percentage of saponifiable fat (58.8%) (Huang&Chang, 1985).

The unsaturated fatty acids are present in high level due to high content of of linoleic acid (69.91%) in total fatty acids of *V.volvacea*(myristic acid 0.48%, palmitic acid 10.5%, palmitoleic acid 0.62%, stearic acid 3.47%, oleic acid 12.74% and linoleic acid 69.91%)(Huang&Chang,1989).Saturated fatty acids present in animal fats are harmful to our health, unsaturated fatty acids on the other hand are very much essential parts of our diet (Holman, 1976).These mushrooms being rich in unsaturated fatty acids and linoleic acids are considered as healthy foods.

Table 2. Composition of EAA[a] of edible straw mushrooms

Amino acids	*V. volvacea* (Chang&Miles,1989)	*V. diplasia* (Chang&Miles,1989)	*V. bombycina* (Cheung,2008)	Hen's Egg[e]	FAO/WHO requirement[f]
Valine	5.4	9.7	3.58	7.3	3.5
Leucine	4.5	5.0	5.01	8.8	6.6
Isoleucine	3.4	7.8	5.41	6.6	2.8
Threonine	3.5	6.0	4.65	5.1	3.5
Methionine	1.1	1.2	0.122	3.1	2.5[c]
Lysine	7.1	6.1	5.41	6.4	5.8
Phenylalanine	2.6	7.0	6.02	5.8	6.3[d]
Tryptophan	1.5	1.5	ND	1.6	1.1
Histidine	3.8	4.2	----	2.4	1.9
Cysteine	---	---	1.91	--	---
Tyrosine	---	---	4.58	--	---
Total EAAs	32.9[b]	48.5[b]	36.692	47.1	32.8

[a] Data given: Amino acids (g) per 100 g of sample
ND: Not determined
[b]Excluding arginine and cystine, [c]Including methionine and cystine,
[d]Including tyrosine and phenyl alanine
[e]For comparison, [f]Data FAO/WHO(1990)

Table 3. Comparative vitamin and minerals composition (dry weight basis) of edible straw mushrooms

Parameter	*V. volvacea* (Ahlawat& Singh, 2016)	*V. diplasia* Chang&Hayes , 2013)	*V. bombycina* (Ahlawat& Singh, 2016)
Vitamin D (IU/g)	462.05	---	106.995
Calcium (mg/100g)	39.74	58.0	25.61
Potassium (%)	4.16	3.353	4.12
Iron (mg/Kg)	72.51	177.0	72.50
Copper (mg/Kg)	42.55	---	50.20
Zinc (mg/Kg)	94.28	---	119.95
Sodium (mg/Kg)	345.34	ND	---
Magnesium (%)	0.11	---	0.12

ND: Not determined

A healthy and balanced diet should necessarily contain high proportion of fiber. It is well known that, foods rich in fiber can reduce a diabetic patient's daily requirement of insulin through stabilizing the blood sugar level (Anderson&Ward, 1979).The

fiber content is 11.90%, 17.40% and 24.60% in *V.volvacea, V. diplasia and V. bombycina*respectively (Table1).Mushrooms contain necessary vitamins like vitamin C, thiamine, riboflavin, niacin and biotin. These three mushrooms are important source of vitamins and minerals.(Ahlawat&Singh, 2016;Chang&Hayes, 2013) (Table 3).

III. PROCEDURES: EXTRACTION AND PURIFICATION

Mushroom polysaccharides can be extracted from cell wall of fungi. Cell walls of mushrooms (fungi) are rich source of two important types of polysaccharides namely chitin (or cellulose) & α,β-glucans and glycoproteins (Ruiz-Herrera,1956).The extraction method is largely dependent on the structure of cell walls.The fruit bodies or cultured mycelia release polysaccharides upon extraction with hot water (Mizuno, 1996). Water-soluble polysaccharides are obtained mainly through hot water extraction, but polysaccharides insoluble in water could be obtained throughextraction with hot alkali (using 5% NaOH).

Impurities from the extracted polysaccharides may be separated through different techniques e.g.repeatedprecipitation from ethanol &AcOH, Size exclusion chromatography (SEC), affinity chromatography and cation and anion ion-exchange chromatography (Zhang&Wang,2007) etc.Water-soluble polysaccharides can be dialyzed through DEAE cellulose bag (Sigma-Aldrich) so as to exclude materials of low molecular weight (preserving MW>12,400).

A. Structural Analysis

1) Chemical methods

Sugar composition is identified by chromatographic studies with the hydrolyzed product.TFA has been used to degrade polysaccharide (glycosidic linkages) as TFA is volatile. Absolute configuration (D or L) of these monosaccharides are identified through reacting with optically active 2-octanol or 2-butanol in acid medium by the method based on Gerwig et.al (Gerwig&Vliegenthart, 1978;Gerwig&Vliegenthart, 1979).

One of the most important chemical methods that identify the mode of linkages of every monosaccharide units in a polysaccharide is methylation analysis. Even though NMR spectroscopy can provide such information nondestructively, methylation, alone or being supported by NMR data is an authoritative method in structural analysis of carbohydrate (Purdie&Irvine, 1903; Haworth, 1915; Ciucanu&Kerek, 1984).

Polysaccharides have the potential to react with oxidizing agents such as HIO_4 or $NaIO_4$ due to the presence of free hydroxyl groups. Non-terminal units e.g. (1→2) and (1→4)-linked hexopyranose units consume one equivalent of periodate per mole yielding a dialdehyde. Whereas branching at the position of C-2 or C-4 or hexopyranose unit with (1→3)-linked remain unchanged by this reaction due to absence of adjacent –OH groups. So the periodate oxidation study further supports the linkages of sugar units as determined by methylation experiments.

Smith degradation is a chemical analysis that degrades a polysaccharide to oligosaccharides and modified polysaccharide. This method is utilized to identify the repeating unit by elimination of few residues selectively.

2) NMR Analysis

Nuclear Magnetic Resonance (NMR) is the most powerful and non-destructive technique for determination of structure of polysaccharides that include monosaccharide unit identification, interpretation of α or β anomeric configuration, mode of linkages and sequence of monosaccharide units of sugar in the repeating unit of the polysaccharide.The protons of anomeric region appear in a clearly different region than that of the other protons in the spectrum. More over the higher splitting constant value of the doublets clearly indicate β- anomers, whereas the lower values correspond to α-anomers.The one bond ^{13}C-^{1}H couplings constant are useful for the determination of anomeric configuration of sugar residues (Bock&Thøgersen, 1983; Bock&Pedersen, 1984; Perlin&Casu, 1969).

Complete structural elucidation requires both 1D (^{1}H and ^{13}C NMR) and 2D (DQF-COSY, COSY, TOCSY, NOESY, ROESY, HSQC and HMBC) NMR techniques for polysaccharide (Bock&Pedersen, 1974; Agarwal, 1992; Gruter& Vliegenthart,1993;Kalsi,2005).COSY(Correlation spectroscopy) identifies pairs of protons, which are coupled to each other. COSY or DQF-COSY (Double quantum filtered correlation spectroscopy) gives information about the protons of an individual sugar residue through a three-bond coupling. A TOCSY (Total correlation spectroscopy) spectrum correlates protons with same spin system through short range as well as long range couplings. It is necessary to identify individual monosaccharide residue. The NOESY (Nuclear overhauser enhancement spectroscopy) spectrum gives information not through bond couplings but through space. NOESY experiments give information on linkages and sequence of sugar residues in a polysaccharide. ROESY (Rotating frame overhauser enhancement spectroscopy) is used to determine signalsof protons which are near in space but not linked by chemical bonds closely. ROESY experiment is necessary when NOESY signals are weak as they are close to the transitions between negative and positive. In HSQC (Heteronuclear single quantum coherence) NMR spectrum all signals correlate directly between a proton and a carbon. An HMBC (Heteromultiple bond coherence spectroscopy) experiment provides coupling with high sensitivity between carbon and proton (two or three bonds)in long range. HMBC experiments set up correlation of multiple bonds through glycosidic linkages and gives necessary information on sequence and linkage of sugar residues jointly with NOESY in a polysaccharide.

IV. STRUCTURAL FEATURES AND BIOLOGICAL ACTIVITY

The enzyme, endo-α-mannanase (Khowala & Sengupta, 1985) purified from the culture filtrate of *V. volvacea* through the

Table 4. Structural characteristics (linkages) of different polysaccharides from straw mushroom sources

Fungi source	Polysaccharide [References]	Linkages	Structural features	
			Main chain	Branch
V. volvacea	Mannogalactan(Misaki&Kinoshita, 1986)	(1→6)-α-D-galactose	(1→6)-α-D-galactose	α-D -mannosyl group
	Homoglucan (Kishida&Misaki, 1989)	(1→3)-β-D-glucosewith (1→6) branching	(1→3)-β-D-glucose	(1→6)-β-D-diglucosyl or one glucosyl groups.
V. diplasia	Heteroglucan (Ghosh&Islam,2008a)	Linear (1→6)-α-D-mannose,(1→4)-α-D-glucose,(1→2,4,6)-β-D-glucose with (1→2) , (1→6) branching	(1→4)-α-D-glucose,(1→4)-β-D-glucose&,(1→6)-α-D-mannose (Ratio,1:1:1) Fr-I	(1→6)-α-D-galactosyl& (1→2)-β-D-glucosyl
	Homoglucan (Ghosh&Islam,2008b)	Linear (1→4)-α-D-glucose,(1→6)-β-D- glucose,(1→4,6)-α-D-glucosewith(1→6) branching	(1→6)-β-D- glucose (1→4)-α-D-glucose (Ratio 1:2) Fr-II	(1→6)-β-D- glucosyl Group
	Heteroglucan (Ghosh,2017)	(1→2,4)-β-D-glucose with(1→2) branching and (1→3)-α-L-fucose	(1→4)-β-D-glucose (1→3)-α-L-fucose (Ratio 1:1)	(1→2)-α-D-galactosyl group
V. bombycina	Heteroglucan (Das&Islam,2008)	(1→6)-β-D-glucose (1→4,6)-α-D-Mannose. with (1→2) branching and (1→6)-α-D-glucose	(1→6)-β-D-glucose (1→6)-α-D- Mannose & (1→6)-α-D-glucose (Ratio,1:1:1)	(1→4)-α-D-glucosyl group

process of precipitation from acetone, ion-exchange and GPC(Bio-gel P-300) showed maximum activity at pH 5.0 at 55ºC on baker's yeast α-mannan.

The mannogalactan,(Misaki&Kinoshita,1986) was isolated from the cold aqueous extract of *V. volvacea*, had a molecular weight of 4 x 10^5 Da composed of an α-(1→6)-D-galactose backbone, 1 out of every 3 D-galactose residues being substituted with a single α-D-mannosyl group (Table 4, Fig-1). The glycogen, purified from the hot aqueous extract of fruiting body of *V. volvacea*, had a molecular weight of 12 x 10^5 Da.

α-D-Man*p*
1
↓
2
→6) α-D-Gal*p* (1→6) α-D-Gal*p* (1→6) α-D-Gal*p* (1→

Fig-1: The repeating unit of polysaccharide isolated from cold aqueous extract of *V.volvacea*

A polysaccharide (Kishida&Misaki, 1989a) isolated from the cold alkali-extract on the other hand released a branched glucan with a back bone of β-(1→3)-linked D-glucose residue, 1 out of 5 or 6 being substituted at *O*-6 with one glucosyl or β-(1→6)-linked diglucosyl units (Table 4, Fig-2).Potent growth of implanted tumors in mice was inhibited by this polysaccharide.

β-D-Glc*p* β-D-Glc*p*
1 1
↓ ↓
6 6
→3) β-D-Glc*p* (1→3) β-D-Glc*p* (1→3) β-D-Glc*p* (1→

Fig-2: The repeating unit of polysaccharide isolated from cold alkali extract of *V. volvacea*

Hypocholesterolemic activity was exhibited bymycelial extracellular polysaccharides in mice with alimentary-inducedhypercholesterolemia. Cheung (Cheung,1996) fed male Sprague-Dawley rats with two semi synthetic diets supplemented with 2% cholesterol as well as extracellular polysaccharide (1% β-glucan) extracted from two different liquid cultures of *V. volvacea* mycelium containing different carbon sources. Mushroom mycelia had higher TDF (Total dietary fiber) value than did the fruiting bodies.

VolvatoxinA2,isolated from *V.volvacea*.is hemolytic and ion channel disturbed cardiotoxic protein (Lin&Chen, 1974). Volvarin, a novel ribosome inactivating protein, isolated from

Table 5. Structural features of polysaccharides from different hybrid straw mushrooms

Fungi source	Polysaccharide [References]	Linkages	Structural features	
			Main chain	Branch
Somatic hybrid of*V.volvacea*&*Pleurotusflorida*[Pflo Vv5 FB]	Homoglucan (Badalyan,2003)	(1→6)-β-D-glucose	(1→6)-β-D-glucose	----
Somatic hybrid of*V.volvacea*&PfloVv12 *(Hybrid of Pleurotusflorida*&*V.Volvacea)*	Homoglucan (Das&Islam,2010)	(1→6)-β-D-glucose	(1→6)-β-D-glucose Fr-I	-----
	Heteroglucan (Das&Islam,2010)	(1→2,6)-α-D-glucose with (1→2)-branching and(1→6)-β-D-galactose	(1→6)-α-D-glucose (1→6)-β-D-galactose (Ratio,1:1) Fr-II,III	(1→2)-β-D Mannosyl Group
	Homoglucan(Sarkar,Islam, 2012)	(1→6)-β-D-glucose	(1→6)-β-D-glucose Fr-I	----
	Homoglucan (Nandan&Islam, 2011)	(1→3)-β-D-glucose,(1→3,4)-β-D-glucose with (1→4)-branching	(1→3)-β-D-glucose (1→3)- β-D-glucose Fr-II	(1→4)-β-D glucosyl group

Somatic hybrid of *V. volvacea*& *Pleurotusflorida*[Pflo Vv1a FB]	Heteroglucan (Bhunia&Islam,2012)	(1→3)-,(1→6)-, (1→3,4)-linked and terminal β-D-glucose along with (1→2,6)-linked α-D-galactose and terminal α-D-mannose	(1→3)-,(1→6)-,(1→3) β-D-glucose(1→2,)- α-D-galactose	(1→6)-α-DMannosyl group and (1→4)-β-D glucosyl group

V.volvacea (Yao&Ooi, 1998) has been found to inhibit the protein synthesis in reticulocyte lysate system of rabbit with an IC_{50} value of 0.5 nM.

A novel lectin (VVL),(She&Liu,1998) isolated from the fruit bodies and cultured mycelia of *V.volvacea*, was ahomodimeric protein lacking any carbohydrate moiety. Thyroglobulin inhibited its hem agglutinatingactivity. It exhibited its immunomodulation throughstimulation of the murine splenic lymphocytes.

V.volvacea produced a multicomponent enzyme system (Cai&Chang, 1999) consisting of endo-1,4-β- glucanase, cellobiohydrolyse and glucosidase for the conversion of cellulose to glucose.

Volvariella volvacea lectin (VVL), separated from *V.volvacea* mushroom was an immunomodulatory lectin. It stimulated the proliferative activity and Th1 cytokines of mouse splenocytes (Chiu&Chang, 1995). Antioxidant activity and protective effect of mushroom, *V.volvacea* was observed on oxidative DNA damage (Lee&Jang, 2004). The medicinal mushroom is used as dietary fiber (Cheung, 1996).

The antitumor activity (Kishida&Misaki, 1989b) of the polysaccharides was demonstrated in mice bearing Sarcoma-180. These can also reduce blood pressure (Ooi, 2001), exhibits a cardiovascular response (Chiu&Pang, 1995) and affect the biosorptions (Dey&Bandyopadhyay,1995; Mohanty&Chaudhury , 2002) of heavy metal ions.

The aqueous extract of mushroom *Volvariella diplasia* was composed of mannogalactosyl glucose (Fr.I, Fig-3) (Ghosh&Islam, 2008a)with molecular weight ~ 1.76 x 10^5 Da. The glucan (Fr.II, Fig-4), (Ghosh&Islam, 2008b) isolated from the hot water extract of fruit body of *V.diplasia*, had a molecular weight of ~70,000 Da. Another heteroglycan, purified from alkali-treated fruit bodies of *V. diplasia* showed macrophage, splenocyte and thymocyte activation (Ghosh, 2017) (Table 4,Fig-5).

Two strains of *Volvariella diplasia*(VdIIHR and VdTNAU*)* and three of *V.volvacea* (VvIARI, VvMU and VvTNAU) were screened (Phutela&Kapoor,1996) for the production of cellulases and xylanases. These VdIIHR and VdTNAU strains

exhibited maximum activity of cellulases and xylanases respectively.

A heteroglycan was purified from hot aqueous extract of *V.bombycina* mushroom (Das&Islam,2008).It was consisted of mannose, glucose and galactose (Table 4, Fig-6).Mushroom contains some bioactive secondary metabolites; ergosta-4, 6, 8(14), 22-tetraene-3-one, indole-3-carbox aldehyde, indazole and ergosterol peroxide in liquid culture (Xu&Yoo, 2010).

Table 6.Biological activity of different straw mushrooms and their hybrids

Fungi source	Polysaccharide source	Biological activity	References
V. volvacea	Mycelium	An extracellular polysaccharide showed hypocholesterolemic activityin mice.	Cheung, 1996
	Fruiting body	This polysaccharide inhibited potent growth of implanted tumors in rats	Kishida&Misaki, 1989
		Blood pressure decreased by this polysaccharide	Ooi,2001
		Showed cardiovascular response	Chiu & Pang,1995
		Effect the biosorptions of metal ions	Mohanty& Chaudhury, 2002
		Stimulated the proliferative activity and Th1 cytokinesof ratssplenocytes	Sze& Liu,2004
		Antioxidant activity and protective effect of mushroom	Lee&Jang,2004
V.diplasia		Polysaccharide showed antioxidant activity	Badalyan& Garibyan 2003
		Polysaccharide showed macrophage, splenocytethymocyte activation	Ghosh, 2017
V. bombycina	Cultured broth	Isodeoxyhelicobasidin,anovel human neutrophil elastase inhibitor	Xu&Yoo,2009
	Fruiting body	Antibacterial activity	(Jagadeesh &Ayyappan, 2010)
Pflo Vv5 FB		Glucan showed the splenocytes,thymocytesand macrophages,	Das& Islam, 2010
Hybrid of *V. Volvacea*& PfloVv12	Fruiting body	Glucan stimulated the immune system and used as antioxidant materials	(Nandan &Islam, 2011)
Pflo Vv1a FB		This polysaccharide showed strong immune enhancing activity	Sarkar& Islam 2012

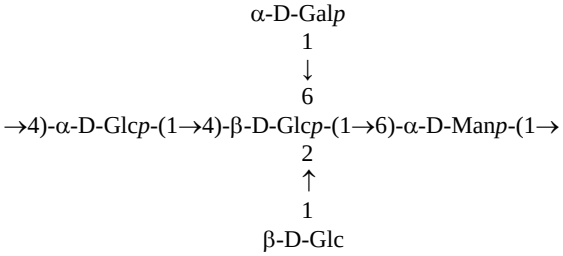

Fig-3: The repeating unit of polysaccharide (Fr.I) isolated from aqueous extract of *V.diplasia*

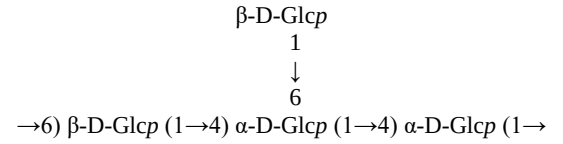

Fig-4: The repeating unit of glucan (Fr.II) isolated from aqueous extract of *V. diplasia*

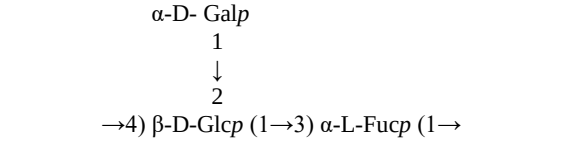

Fig-5: The repeating unit of polysaccharide isolated from alkali extract of *V.diplasia*

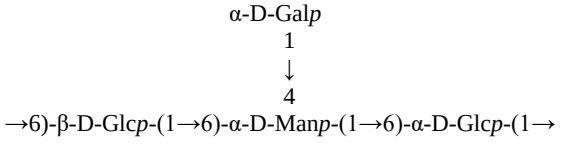

Fig-6: The repeating unit of heteroglycan isolated from aqueous extract of *V.bombycina*

Isodeoxyhelicobasidin, isolated from the *V.bombycina* culture broth, acted as a novel human neutrophil elastaseinhibitor(Xu&Yoo, 2009).

V. ENVIRONMENTAL POTENTIAL

Fungal phyto remediation (Prakash, 2017; Ali&Sajad, 2013) ormycoremediation is another system of bioremediation where soil and water can be decontaminated from harmful materials

using the natural degradative abilities of certain fungi. The soil of industrial areas is contaminated with pollutants like heavy metals (Dey&Bandyopadhyay,1995), PCB (Polychlorinated biphenols), pesticides and other radioactive wastes. Mushrooms can absorb toxins directly into their tissues especially heavy metals when these are growing in polluted environment.

The up taking (Purkayastha&Mitra,1992) of a few metals by *V. volvacea* during submerged growth of the organism. *V. volvacea* was observed to uptakesome metal ions likeHg^{2+}, Cu^{2}, Co^{2+}, Cd^{2+} and Pb^{2+}sufficiently below their respective lethal concentrations. The maximum and minimum uptake of Pb^{2+} and Cd^{2+} was 100 micrograms g-1 and 2.93 micrograms g-1respectively by sporocarps when spawned substrate was treated with different metal salts separately. The bio-effectiveness of sporocarp production was significantly decreased by Co^{2+}. $Cd^{2+}$was considered toxic to mycelia, whereas sporocarps were affected by Co^{2+}. Among these above mentioned metal ions,mycelia and sporocarps were found to uptake maximim amount of Cu^{2}, and Pb^{2+} respectively. Mushrooms are used in many countries forthe detoxification of PCB (Polychlorinated biphenols), PCP (Pentachlorophenol), oil,pesticide and herbicide residues (Chiu&Moore, 1998).

Table7. The uptakes of different metals by fungal species (phytoremediation)

Fungi source	Metals (uptaking)	References
V. volvacea	Zn, Cd, Cu,Pb, Fe Ni	Lamrood& Ralegankar,2013
V.diplasia	Cd,Cu, Ni,Pb	Lamrood& Ralegankar,2013

VI. RECYCLING AGRICULTURAL WASTES AND PRODUCTION OF ENZYMES

The millions of tons of agricultural wastes like straw, corn cobs, grass, sawdust, sugarcane bagasse, cotton waste, coffee pulp oil palm waste, water hyacinth plants, coconut husk, tree leaves and branches from farms, plantations and factories, are discarded, burned or dumped that create environmental pollution. These wastes can be used to create mushroom growing substrate (Garcha&Phutela, 1981; Stamets, 1993).The enzymes of amylase, cellulase and laccase are the extra cellular enzymes produced by *V. Volvacea*, *V.diplasia* and *V. bombycina.* Optimal pH for cellulose production was 5.0 at 50ºC for *V. Volvacea*. In shake flask culture,cellulolytic activity was maximum within 5 days (Chang & Steinkraus, 1982). Cellulolytic enzymes were produced by *V. diplasia* (Puntambekar, 1995) during its growth in shake culture using 0.5% cellulose powder as carbon source at pH 5.4, 28ºC.Eco friendly conversion of lignocellulosic residues can be made economically one of the most feasible processes through production of edible mushrooms. (Bano&Rajarathnam, 1993; Cohen & Hadar, 2002).Growing *Volvariella* species from lignocellolostic waste is an evolving process for development of protein rich foods froma renewable source that will help maintaining security of food for the common people in developing countries (Sanchez & Esqueda, 2002).It was observed that *V. volvacea* can produce different cellulolytic enzymes which are not recognized as lignin-degrading enzymes (Buswell & Yu, 1996).

CONCLUSION

Straw mushrooms areconsidered as excellentnatural foodwith a potential to maintain good health and improving human immune system and are recognized as rich sources of several bioactive components exhibiting antibacterial, anticancer, antioxidant, antitumor, cytotoxic, anti-HIV and hypocholesterolemic activities. The β-glucans have maximum bioactivity in these mushroom polysaccharides. At par nutritional attributes and production of enzymes, it is better choice for cultivation of straw mushrooms (*Volvariella* species) at Industrial scale for food security in developing countries and control the air pollution associated with burning agriculture wastes into the environment. Several *Volvariella spp.* identified so far have been found to effectively remove heavy metal contamination. The 'mycoremediation' process is a novel technology that is advanced, eco-friendly and economic as well. Thus, it seems to be economically, nutritionally pharmaceutically and environmentally very important and useful species.

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