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Mini-review on edible mushrooms as source of dietary fiber: Preparation and health benefits

Peter C.K. Cheung *

Food and Nutritional Sciences, School of Life Sciences, The Chinese University of Hong Kong, Hong Kong, China

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Abstract

Dietary fiber and high-fiber food products have attracted great attention because of their significant health benefits to consumers. Mushrooms are valuable resources for food, medicine and nutraceuticals. Edible mushroom is considered as a novel source of dietary fiber. The dietary fiber content and composition in edible mushroom vary greatly with its morphological stages including fruit body, mycelium and sclerotium. The focus of this mini-review is on the preparation of dietary fiber from edible mushroom with emphasis on the sclerotium which has the highest level of non-starch polysaccharides. The possible health benefits of mushroom dietary fiber in relationship with boosting the immune system, anticancer functions as well as the control of blood lipids and glucose levels are also discussed.

Keywords: Dietary fiber; Edible mushrooms; Health benefits; Preparation

1. Definition of dietary fiber

The definition of dietary fiber (DF) proposed by American Association of Cereal Chemists (AACC) defines DF being made up of edible part of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine as well as having beneficial physiological effects such as laxation, blood glucose attenuation and/or blood cholesterol attenuation [1]. More specifically, dietary fiber means carbohydrate polymers with ten or more monomeric units, which are not hydrolyzed by the endogenous enzymes in humans [2]. These non-digestible carbohydrate (NDC) polymers should occur naturally in the food as consumed and have been obtained from food raw material by physical, enzymatic or chemical means and which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities [2].

2. Demand for DF and its products

The increasing public awareness of DF's potential health benefits has greatly encouraged food manufacturers to develop a wide range of fiber-enriched or fiber-fortified food products [3,4]. Nowadays, most DF ingredients (such as cereals-based, fruits-based, and legumes-based DF) are originated from the by-products of their corresponding food processing (*e.g.* milling, juice extraction, de-hulling, etc.) followed by different refining steps (such as grinding, sieving, bleaching, defatting, etc.) in order to meet a wide range of customers' requirements [5–7]. Because of the highly competitive market of fiber-enriched food products, exploration of alternative source of DF as well as DF preparation method is urgent needed [8].

3. DF and human health

It has been demonstrated by extensive research in the past three decades that sufficient DF intake has benefits for health maintenance and disease prevention including cardiovascular disease, diabetes, cancer and weight regulation [9–13]. Therefore, DF research has drawn much attention recently, particularly in the growing nutraceutical industry [14,15]. DF of different origins has different structures, chemical composition, and

* Corresponding author at: Food and Nutritional Sciences, School of Life Sciences, The Chinese University of Hong Kong, Hong Kong, China. Tel.: +852 39436144; fax: +852 26037246.
E-mail address: petercheung@cuhk.edu.hk
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Table 1
Proximate composition of some common mushroom species.[a]

Species	Common names	Crude protein[b]	Crude fat	Carbohydrate[c]	Crude fiber[d]	Ash	Reference
Agaricus bisporus	Button Mushroom	23.9-34.8	1.7-8.0	51.3-62.5	8.0-10.4	7.7-12.0	[23]
Auricularia auricula-judae	Black Fungus	8.1	1.5	81.0	6.9	9.4	[23]
Boletus edulis	Cep	29.7	3.1	51.7	8.0	5.3	[23]
Cantharellus cibarius	Chanterelle	21.5	5.0	64.9	11.2	8.6	[23]
Grifola frondosa	Maitake	21.1	3.1	58.8	10.1	7.0	[24]
Hericium erinaceus	Monkeyhead	22.3	3.5	57.0	7.8	9.4	[24]
Lentinus edodes	Shiitake	13.4-17.5	4.9-8.0	67.5-78.0	7.3-8.0	3.7-7.0	[23]
Pleurotus ostreatus	Oyster Mushroom	10.5-30.4	1.6-2.2	57.6-81.8	7.5-8.7	6.1-9.8	[23]
Tremella fuciformis	White Jelly Fungus	4.6	0.2	94.8	1.4	0.4	[23]
Tricholoma giganteum	Matsutake	16.1	4.3	70.1	4.5	5.0	[24]
Tuber melanosporum	Black Truffle	23.3	2.2	66.2	27.9	8.3	[23]
Vovariella volvacea	Straw Mushroom	30.1	6.4	50.9	11.9	12.6	[23]

[a] All data presented as percentage of dry weight.
[b] The nitrogen factor used for crude protein calculation was 4.38.
[c] The carbohydrate content was calculated by subtracting difference.
[d] The crude fiber contains mainly the water-insoluble fiber fraction.

physico-chemical properties that would exhibit different nutritional, technological and physiological benefits [16,17].

4. Mushrooms as source of DF

Compared to other conventional sources of DF, such as cereals, fruits, legumes and vegetables, mushrooms or fungi are underutilized [7,8]. In fact, edible mushrooms or macrofungi are a rich source of some novel DFs that have various beneficial health effects to humans which are discussed below.

Mushrooms are defined as fungi that have distinctive and visible fruiting bodies [18] and they include edible and medicinal ones. The fruiting bodies of edible mushrooms (*e.g. Lentinus edodes*) are mainly consumed in their flesh or dried form, while medicinal mushrooms (*e.g. Ganoderma lucidum*) are non-edible fungi that have biopharmaceutical applications due to the bioactive components such as polysaccharides and triterpenoids that they contain.

While plant cell walls are major sources of DF, mushroom cell walls can also be considered as DF. Mushroom cell walls contain a mixture of fibrillar and matrix components which include chitin (a straight-chain (1→4)-β-linked polymer of *N*-acetyl-glucosamine) and the polysaccharides such as (1→3)-β-*D*-glucans and mannans, respectively [19]. These mushroom cell wall components are non-digestible carbohydrates (NDCs) that are resistant to human enzymes and can be considered as source of DF.

Carbohydrate is a major component in mushrooms and its total content ranges from 35% to 70% dry weight (DW) with variations in different species (Table 1) [20,21]. Most of the carbohydrates in mushrooms are NDCs including oligosaccharides such as trehalose and cell wall polysaccharides such as chitin, β-glucans and mannans. The level of chitin found in different mushrooms is usually only a few % dry matter (DM), while the content of β-glucans can be much higher [22].

There is large variation in the DF content of mushrooms between different species (Table 2). Mushroom DF is constituted mainly by water-insoluble ones (IDF), with chitin and β-glucans being the most representative ones, while the level of water-soluble ones (SDF) is usually less than 10% DM as shown in Table 2. Consumption of edible mushrooms as part of our daily diet can easily provide up to 25% of the recommended dietary intake of DF [20].

Table 2
Composition of dietary fiber in some cultivated mushrooms (% dry matter).

Mushroom species	TDF (%)	IDF (%)	SDF (%)
Aa	26.7 ± 1.51	26.2 ± 1.29	0.51 ± 0.22
Ab	29.6 ± 3.52	27.6 ± 2.29	1.93 ± 1.24
Ac	36.4 ± 1.01	34.9 ± 0.95	1.52 ± 1.53
Cc	34.6 ± 5.28	32.8 ± 4.20	1.79 ± 1.13
Fv	38.2 ± 2.77	33.8 ± 1.93	4.42 ± 0.99
Gf	44.0 ± 1.55	43.1 ± 1.43	0.91 ± 0.13
He	34.0 ± 0.98	31.8 ± 0.56	2.12 ± 0.42
Hm	32.0 ± 1.35	30.1 ± 1.60	1.89 ± 0.26
Hr	26.9 ± 0.84	23.6 ± 0.29	3.25 ± 0.93
Lg	34.8 ± 0.53	34.3 ± 0.76	0.50 ± 0.26
Pa	30.8 ± 0.48	27.7 ± 0.67	3.08 ± 0.20
Pn	37.9 ± 0.79	34.8 ± 0.77	3.15 ± 0.11
Sra	28.4 ± 0.91	26.2 ± 0.80	2.26 ± 0.31

Agrocybe aegerita (*Aa*); *Agaricus blazei* (*Ab*); *Agrocybe chaxinggu* (*Ac*); *Coprinus comatus* (*Cc*); *Flammulina velutipes* (*Fv*); *Grifola frondosa* (*Gf*); *Hericium erinaceus* (*He*); *Hypsizigus marmoreus* (*Hm*); *Hericium ramosum* (*Hr*); *Lentinus giganteus* (*Lg*); *Pholiota adiposa* (*Pa*); *Pholiota namkeo* (*Pn*); *Stropharia rugoso-annulata* (*Sra*). Modified from Ref. [22].

5. Mushroom sclerotia as novel DF

Some mushrooms can develop a morphological form called sclerotium which has a compact mycelial structure under unfavorable conditions and remain dormant until the environment is suitable for its development of fruiting bodies for reproduction [25]. The major cell wall components of mushroom sclerotium are chitin and β-glucans with β-1,3 backbone and β-1,6-linked side branches [26–28]. These sclerotial cell wall components cannot be digested by human enzymes and therefore can be regarded as novel source of DF by definition [1,2].

Our previous studies have found that the total DF content of three mushroom sclerotia, namely *Pleurotus tuber-regium*, *Polyporus rhinocerus* and *Wolfiporia cocos* was extremely high and could be well over 80% DM [28–30]. In the sclerotium of *P. tuber-regium*, IDF constituted almost 80% DM while SDF had only 2.50% DM [30]. Such high level of total DF content found in mushroom sclerotium is similar to that of commercial DF obtained from conventional sources such as seaweeds and legumes [31]. It was found that the predominant sugar residues in the DF of the sclerotium of *P. tuber-regium* was glucose (about 90%) followed by about 6% glucosamine, confirming that β-glucans and chitin are the main cell wall polysaccharides [29].

6. Preparation of mushroom DF

The main principles of DF preparation are the removal of non-DF materials by either enzymatic or chemical methods. SDF is extracted by water or other aqueous solution with pH control while IDF is usually recovered as insoluble residue. The most widely accepted method for total DF determination is the AOAC enzymatic-gravimetric methods 985.29 [32] involving the use of three analytical enzymes: heat stable α-amylase (EC 3.2.1.1), protease (EC 3.4.21.14) as well as amyloglucosidase (EC 3.2.1.3) to remove all the non-fiber materials including starch and protein. Chemical methods for DF preparation are usually simple but non-specific with possible loss or degradation of DF.

Comparing to fruit body and mycelium, mushroom sclerotium has the highest level of NDCs and potential to an ideal source of commercial DF. Recently, an enzymatic procedure modified from the AOAC methods 985.29 for preparing some novel DF from three mushroom sclerotia including *Pleurotus tuber-regium* (PTR), *Polyporus rhinocerus* (PR) and *Wolfiporia cocos* (WC) using analytical and industrial food grade enzymes was developed in our laboratories [30,33]. The effects of these enzymes on both the yield and NDC composition of sclerotial DF were compared. It was found that the use of industrial grade enzymes in the preparation the total DF could give a very high yield of sclerotial DFs [PTR: 81.2%; PR: 86.5%; WC: 96.2% DW] with purity that was comparable to that of analytical enzymes [33,34]. Moreover, sclerotial DF also has functional properties such as water and oil holding, emulsifying and mineral binding that are essential for its application in food products [30]. Together with the advantages of energy saving, environmental friendly, non-toxic, and specific, the enzymatic approach in the scale-up preparation of the sclerotial DF in food industry is worthy for further exploration.

7. Health benefits of mushroom DF

Compared to Asian countries such as China, Korea and Japan, the application of medicinal mushrooms in the Western countries is more recent [35–37]. Medicinal mushrooms are characterized by having cell wall polysaccharides and proteins as well as fungal secondary metabolites including lignins, triperpenes and phenolics that have a broad spectrum of pharmacological activities [35,36]. On the other hand, edible mushrooms are rich in DF with NDCs including β-glucans, polysaccharide–protein complexes (PSPC) and chitin that also has a wide range of health benefits to humans. The beneficial health effects of mushroom DF that have been studied include the immune-enhancing and antitumor activity as well as blood glucose and lipid attenuation [38–43]. Some commercial β-glucans isolated from the fruiting bodies of *Lentinus edodes* (lentinan) and *Grifola frondosa* (D-fraction) as well as PSPC from *Trametes versicolor* were shown to stimulate the non-specific immune system in animals to inhibit cancer cell proliferation [38]. They are regarded as immunomodulators and have been used as adjuvant in cancer therapy with certain success [44–46]. It has recently been shown that a PSPC isolated from an edible mushroom *Pleurotus pulmonarius* can suppress *in vitro* and *in vivo* liver cancer development and progression through inhibition of VEGF-induced PI3K/AKT signaling pathway [47]. Apart from β-glucans, heteropolysaccharides such as glucuronoxylomannan isolated from the fruiting bodies of *Tremella fuciformis* and *Tremella mesenterica* exhibited immunomodulatory and hypoglycemic effects in animal studies [42,48].

8. Biopharmacological effect of sclerotial DF

As mentioned earlier, mushroom sclerotium is a rich source of DF source and contains extremely high level of β-glucans (>80% DM) that can have a number of biopharmacological effects that are beneficial to humans [49]. It has been reported that both the innate and adaptive immunity of the host could be stimulated by sclerotial β-glucans to trigger strong immunomodulatory mediated by cytokine production and signaling cascade as well as direct inhibition of cancer cells via cell cycle arrest and cytotoxicity [50–54]. Native sclerotial β-glucans isolated from the *P. tuber-regium* could induce apoptosis of acute promyelocytic leukemic cells (HL-60) [52], while their carboxymethylated counterparts could induce both *in vitro* cell cycle arrest and apoptosis of human breast cancer cells (MCF-7) mediated by the down-regulation of cyclin D1 and cyclin E expressions at the G_1 phase as well as and the up-regulation of the expression of the Bax/Bcl-2 ratio, respectively [53]. Chemical modifications of native sclerotial β-glucans from *P. tuber-regium* by carboxymethylaion and sulfation could enhance the immunomodulatory and anti-tumor activities of these new derivatives when they were administered intraperitoneally on BALB/c mice bearing Sarcoma 180 solid tumor [55,56].

The mechanisms of the *in vivo* immunomodulatory and antitumor activities of sclerotial β-glucans are not well understood but it is very likely that some kind of surface receptor interactions between the immune cells and β-glucans might have been involved. Dectin-1 has been identified as a β-glucan receptor found on the surface of a number of innate immune cells including monocytes, macrophages, NK cells and dendritic cells in human and mice recently [57,58]. Dectin-1 receptor was able to recognize β-glucans derived from yeast to trigger immunomodulation in both humans and mice [59,60]. The new approach of identifying similar or novel β-glucans receptor(s) that are specific to sclerotial β-glucans on the surface of innate human primary cells would be a promising new one and would

provide new insights in explaining the immunomodulatory and anti-tumor effects of sclerotial β-glucans [50].

There are other biopharmacological activities of sclerotial polysaccharides isolated from *P. tuber-regium* that have been reported. These include hepatic protection against acute liver injury induced by carbon tetrachloride in mice and lowering of fasting blood glucose level in alloxan-induced diabetic mice [61]. Chemically modified sclerotial β-glucans derived from *P. tuber-regium* also have interesting biological activities that could not be found in their native counterparts. For instance, sulfated sclerotial β-glucans isolated from *P. tuber-regium* possessed anti-viral activity against human simplex virus including HSV-1 and HSV-2 which was probably due to their increased aqueous solubility and more opened chain conformation compared to the native ones [62,63]. Both sulfated and carboxymethylated sclerotial β-glucans obtained from *P. tuber-regium* could scavenge superoxide and hydroxyl radicals and protect the oxidative damage of liver mitochondria and DNA [64–66].

Most recently, it has been demonstrated that sclerotial β-glucans can be utilized by human colonic bacteria *in vitro* and therefore they have the potential to be used as novel prebiotics that can influence human gut health by selectively modulating the growth of probiotic bacteria including bifidobacteria and lactic acid bacteria [67,68]. The colonic fermentation of sclerotial β-glucans isolated from *P. tuber-regium* could also enhance the absorption of calcium and magnesium in ovariectomized rats which might have the health implication of improving mineral absorption in the human gut [69].

9. Conclusion

In general, edible mushrooms are underutilized to be a source of DF at the moment. Given the many mushroom species that have not yet been studied, it is anticipated that more new methods of preparation of mushroom DF and high fiber products enriched with mushroom DF will be developed. With advances in molecular biology nutrigenomics, the structure–function relationship of the bioactive components in mushroom DF, especially β-glucans, can be elucidated more clearly. This would greatly facilitate the application of mushroom DF as functional food ingredient or product that can provide various health benefits to humans in the future.

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