Review Article
Food Science and Technology

ISSN 0101-2061 (Print)
ISSN 1678-457X (Online)

DOI: https://doi.org/10.1590/fst.35422

Extraction, physiological function and application of soluble dietary fiber from edible fungi: a review

Zhipeng ZHENG[1], Wei DENG[1], Yibin LI[2,3]*, HongBo SONG[1]*, Shouhui CHEN[2]

Abstract

Soluble dietary fiber has attracted much attention due to its significant health benefits to consumers. Edible fungi are abundant sources of soluble dietary fiber (SDF). The content and composition of soluble dietary fiber in edible fungi variy greatly according to varieties, growth stages and different parts. This review focuses on the extraction methods of soluble dietary fiber from edible fungi, such as *Lentinula edodes*, *Agrocybe cylindracea*. The possible health benefits of mushroom soluble dietary fiber in relationship with hypoglycemic effect, regulatory mechanism of pancreatic lipase, gut microbiota and macrophages are also discussed. Finally, the application and development potential of mushroom soluble dietary fiber are pointed out.

Keywords: edible fungus; soluble dietary fiber; extraction; physiological function.

Practical Application: Development of soluble dietary fiber food from edible fungi.

1 Introduction

Dietary fiber (DF) is defined as consisting of ten and more carbohydrate polymers that cannot be digested and absorbed in the human small intestine, and are plant matter that is completely or partially fermented in the large intestine, oligomers consisting of three to nine carbohydrate polymers are also considered dietary fibers in some countries. the carbohydrate polymers can be derived from natural foods or obtained from food raw materials by physical and chemical methods, but there must be scientific evidence to prove that they are beneficial to the human body. DF is also called "The seventh nutrient", mainly composed of polysaccharides, oligosaccharides, lignin and other substances (Alyassin & Campbell, 2019; Stephen et al., 2017; Abreu Y Abreu et al., 2021). DF has many uses such as can be combined with classified compounds for human health benefits and regulated the production of short-chain fatty acids by the intestinal flora (Subiria-Cueto et al., 2022; Zhou et al., 2021). Dietary fiber is generally divided into insoluble dietary fiber (IDF) and soluble dietary fiber (SDF). The content of IDF is generally higher than that of SDF. IDF mainly includes cellulose, hemicellulose, resistant starch, etc.. IDF can modulate the composition of gut microbiota to prevent colitis (Tian et al., 2021), increase the volume of feces and reduce postprandial blood sugar by combining with glucose and inhibiting amylase, so as to achieve the effect of preventing diabetes (Qi et al., 2016). Compared with IDF, most people pay more attention to the role of SDF, although SDF only exists in a small amount in most cases. SDF is mainly composed of pectin, gum and some hemicelluloses. SDF can reduce the risk of cardiovascular disease by reducing serum cholesterol (Gunness & Gidley, 2010), and can improve postprandial blood sugar in patients with type 2 diabetes, this is associated with delayed gastric emptying in patients with type 2 diabetes by SDF (Yu et al., 2014). In addition, SDF also has the effects of lowering blood lipids and reducing the risk of coronary heart disease (Chawla & Patil, 2010).

Edible fungi, such as shiitake mushrooms, *Agaricus bisporus*, straw mushrooms, white fungus, black fungus, are very popular among consumers for their unique flavor and medicinal value,etc. Edible fungi contain a large amount of SDF and IDF, which is one of the best ways for health people to consume DF. Adding edible fungi DF powder into pasta can reduce the blood glucose response to pasta (Lu et al., 2018). Nile & Park (2014) measured 20 wild mushrooms, and found that the average total dietary fiber content of all mushrooms was 31.6%, and the average SDF content was 2.85%. So their study found mushrooms such as *Sparassis crispa*, *Lentinus delicious*, *Lentinus quarrulosus*, and *Cantharellus clavatus* are a good source of SDF. This article reviews the research progress of edible mushroom SDF in recent years, and provides a reference for the further utilization of SDF of edible fungus.

2 Effects of different extraction methods on SDF from edible fungi

The methods AOAC (Association of Official Analytical Chemists) (Tobaruela et al., 2018) 991.43 is a traditional DF analysis method, mainly analyzing insoluble and soluble higher molecular weight dietary fiber (HMWDF), while methods AOAC 2011.25 is a new dietary fiber analysis method. This method can not only analyze the content of TDF, but also the content of IDF, SDF and resistant starch (RS) (Tobaruela et al.,

Received 18 Mar., 2022
Accepted 04 May, 2022
[1] *College of Food Science, Fujian Agriculture and Forestry University, Fuzhou, Fujian Province, China*
[2] *Institute of Agricultural Engineering Technology, Fujian Academy of Agricultural Sciences, Fuzhou, Fujian Province, China*
[3] *Fujian Key Laboratory of Agricultural Product (Food) Processing, Fuzhou, Fujian Province, China*
*Corresponding author: lyb9951@163.com; sghgbode@163.com

2018; Yang et al., 2014; Westenbrink et al., 2013). The traditional extraction method of DF may cause the loss in the DF extraction process, and then cause the loss of SDF content, which is prone to the phenomenon that the SDF content in edible fungi is underestimated (Pastell et al., 2019).Therefore, obtaining a more accurate and higher content SDF methods has become one of the important research directions of edible mushroom dietary fiber. Some processing methods and efficiencies are shown in Table 1.

Compared with IDF, the content of SDF is relatively small, but its importance in nutrition and function exceeds that of IDF, so more and more people pay attention to increasing the content of SDF in food through different technologies (Bader Ul Ain et al., 2019a). Common and safer methods include chemically modified (acid treatment, alkaline treatment) and extrusion (Bader Ul Ain et al., 2019b). Extrusion is a common technology in the food industry, reducing the volume of solid particles, changing their physicochemical properties, and potentially leading to the conversion of IDF to SDF (Duque et al.,2017). *Lentinula edodes* was extruded under different conditions by the Orthogonal Design of Experiments. Finally, under the condition of temperature of 130 °C, when the speed reached 125r/min and had 40% water content, which significantly increased the content of SDF to 3.6% (Xue et al., 2019b).

Superfine grinding technique has emerged in recent decades, it is a new processing method that widely used in food, medicine, chemical industry. Grinding food into powder can not only change the physicochemical properties of food, such as changes in chemical bonds, functional groups, surface area and pores caused by superfine grinding, but also bring huge economic potential (Gao et al., 2020). *Lentinus edodes* were subjected to superfine grinding to obtained two powders: superfine grinding cap (SGC) and stipe (SGS). In terms of particle size, SGC and SGS are only 0.54 μm and 0.46 μm, which is far lower than the particle size obtained by shear pulverization. The SDF content of both SGC and SGS was higher than that of the other group using shear pulverization, but TDF had little effect, the SDF content (% of dry basis) of superfine grinding SGC was increased to 15.45%, and the SDF content (% of dry basis) of SGS was increased to 12.55%. It is obvious that the SDF content of SGC and SGS is significantly increased after superfine grinding, which was similar to the results obtained in previous experiments (Zhang et al., 2012), the micronization processing technology can significantly increased the SDF content of *Lentinus edodes*, and the SDF of the cap was generally higher than that of the stipe, its method was superior to physical processing methods such as shearing and mechanical grinding. It shows that the superfine grinding promotes the conversion of IDF to SDF, which is a processing

Table 1. Effects of different processing methods on SDF of edible Fungus.

Species	Method	Process	Extraction effect	Reference
Lentinula edodes	Extrusion	extrusion temperature of 130 °C, water content of 40% and rotation speed of 125 r/min.	Increased the content of SDF to 3.6%.	(Xue et al., 2019b)
	Superfine grinding	Nano-ball-millwith high energy and multi-dimensional swing,adjust the frequency from 5-35 °C to treat mushroom caps and stipe for 6 hours.	The SDF content (% of dry basis) of SGC is increased to 15.45%, and the SDF content (% of dry basis) of SGS is increased to 12.55%.	(Ming et al., 2015)
	Shear pulverise	High-speed pulverizer for 30s, micronizer for grinding and shearing for 20min.	The SDF content (% of dry basis) of shear pulverised cap is increased to 10.77%, and the shear pulverised stipe is increased to 7.94%.	
	Mechanically mill	High-speed pulverizer for 30s, micronizer for mechanically mill for 8 min.	The SDF content of the shear pulverized cap reaches 19.94 g/100 g, and the shear pulverized stipe reaches 13.86 g/100 g.	(Zhang et al., 2012)
	Jet mill	High-speed pulverizer for 30s,Compressed air at 145 psi to process shear pulverized powder.	The SDF content of the jet milled cap reaches 23.62 g/100 g, and the jet milled stipe reaches 15.67 g/100 g.	
Agrocybe cylindracea	Ultrasonic-assisted enzymatic combined with high temperature modification	Liquid material ratio of 30 mL/g, HTM temperature of 125 °C, and time of 50 min.	The proportion of SDF in DF is 6.8%.	(Jia et al., 2020a)
	Ultrasonic-assisted enzymatic combined with cellulase modification	liquid material ratio of 30 mL/g, CEM cellulase concentration of 1.5%, 2.0 hours.	The proportion of SDF in DF is 4.9%.	
	high pressure processing	The temperature of 25 °C, 15 min, and pulverized with a pulverizer.	the SDF content HPP method was 7.00 g/100 g.	(Lv et al., 2014)
	superfine grinding	cut into small pieces and dried, processed with a pulverizer, and then used a micronizer to obtain ultra-fine powder.	the SDF content SG method was 9.63 g/100 g.	

technology that effectively changes the ratio of SDF and IDF (Ming et al., 2015).

Agrocybe cylindracea is rich in dietary fiber (Brennan et al., 2012). Jia et al. (2020a) optimized ultrasonic-assisted enzymatic method for DF extraction in *Agrocybe cylindracea*. Comparing the improved DF with high temperature modification (HTM) and cellulase modification (CEM), part of the IDF was converted into SDF by modification, thereby changing the function and properties of DF. The content of SDF after HTM and CEM treatment has been improved, and the treatment effect of HTM was better than that of CEM. Under the condition that the liquid-material ratio was 30ml/g, the treatment temperature reached 125 °C, and the treatment time was 50min, the proportion of SDF in DF was 6.8% for HTM's gruop. On the other hand, the liquid-material ratio was 30ml/g, the concentration of cellulase treatment reached 1.5%, and the time reached 2.0 hours, the proportion of SDF in DF was 4.9% for CEM's group, which significantly increased SDF and reduced IDF. In other study (Lv et al., 2014), The SDF content of *Agrocybe cylindracea* powder prepared by the superfine grinding method was 9.63g/100g, and the SDF content of Agrocybe cylindracea powder prepared by the high pressure processing method was 7.00g/100g, both methods were higher than the control group's 6.60g/100g. In conclusion, ultrafine pulverization can increase the soluble dietary fiber content of mushroom powder.

β-glucans is a good soluble dietary fiber (Brennan & Cleary, 2005) and added to food as a substitute to increase the content of soluble dietary fiber in food (Sánchez-Madrigal et al., 2015), such as (1-3)(1-4)-β- D-glucans have research prospects for lowering blood sugar and anti-tumor (Iaccarino et al., 2020). Physical treatment is a method to obtain higher beta-glucan content, such as ultraviolet light irradiation, temperature control and extrusion (Ryoo et al., 2018; Khan et al., 2021). The advantages of these physical treatments are low cost and avoidance of contamination from chemical treatment. In addition, Matsuura et al. (2020) found that, although β-glucan was extracted under the same hot water extraction conditions, the β-glucan content (37.2 g/100 g) of *Sparassis crispa* was 20 times higher than that of the unfermented control sample (1.8 g/100 g) after *Lactobacillus paracasei* fermented *Sparassis crispa*. Microorganisms can increase the SDF content of edible fungi.

3 Physiological function of soluble dietary fiber from edible fungi

Soluble dietary fiber has attracted the attention of many researchers because of its superior physiological function. Figure 1 summarizes the physiological function of several soluble dietary fibers from edible fungi.

3.1 Hypoglycemic effect of edible fungi soluble dietary fiber

Type 2 diabetes is a common disease that can cause great harm to human health, but most western medicines for diabetes have side effects, so it is a potential to control blood sugar and relieve diabetes by extracting SDF from edible fungi (Bai et al.,2021; Hua et al., 2022). *Auricularia auricular* polysaccharide belongs to soluble dietary fiber. The polysaccharide extracted from *Auricularia polytricha* has hypoglycemic effect, and the extracted DF has a higher activity of relieving constipation (Xiang et al.,

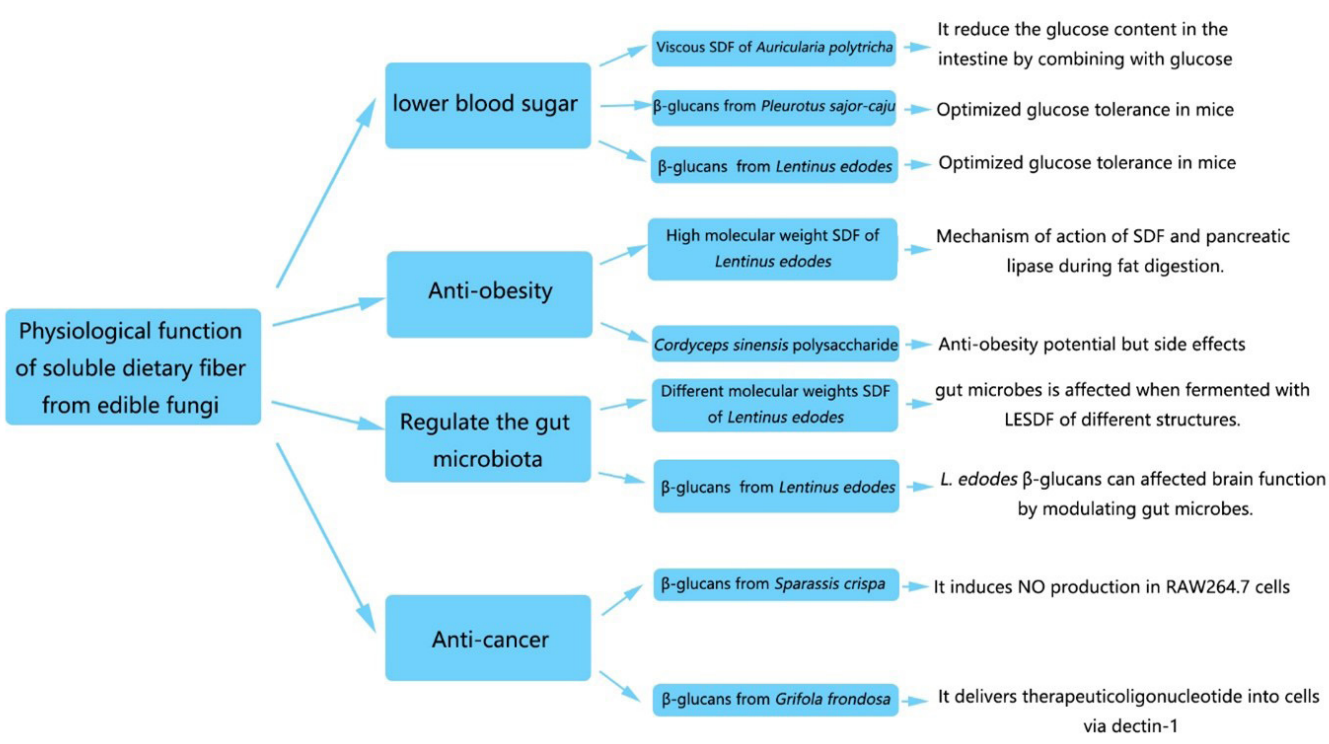

Figure 1. Physiological function of soluble dietary fibers from edible fungi.

2021; Jia et al., 2020b). The viscosity value of *Auricularia polytricha* (wood ear mushroom, WEM) SDS is relatively high, belongs to high viscosity fiber. Jovanovski et al. (2019) had proved that viscous fiber supplements improve conventional markers of glycemic control beyond usual care and should be considered in the management of type 2 diabetes. Adding WEM soluble viscous dietary fiber (0.5%-2%) to 25mL glucose solution (concentration 0.5-100 mmol/l). The effect of different fibers (concentration 2%) on glucose dialysis retardation index (GDRI) is shown in Table 2. Experiments showed that the glucose adsorption capacity of WEM soluble viscous dietary fiber was stronger than that of insoluble dietary fiber (such as cellulose) under various glucose concentrations, and the glucose binding capacity was in a dose-dependent relationship. WEM had a high GDRI, and with time the transition stability was good and showed excellent glucose diffusion delay. The principle of WEM soluble dietary fiber lowering blood sugar may be to reduced the glucose content in the intestine by combining with glucose. Therefore, daily consumption of WEM may had the effected of reducing postprandial blood sugar (Wu et al., 2014). Another of experiments (Kanagasabapathy et al., 2012), C57BL/6J mice developed symptoms of diabetes under high-fat feeding, polysaccharide extracted from *Pleurotus sajor-caju* (GE) contained a large proportion of β-glucans (80.55%), at different doses To fed mice, compare β-glucans to improved their symptoms of blood sugar, and founded that the GE optimized the mice's glucose tolerance, and they did not developed insulin resistance. It showed that GE was a drug with hypoglycemic potential. And β-glucans come from *L. edodes* In long-term experiments, *L. edodes* β-glucans also showed that *L. edodes* β-glucans improved the symptoms of glucose intolerance in HF mice and had hypoglycemic potential (Pan et al., 2021).

3.2 Effects of edible fungi soluble dietary fiber on obesity

Supplementing dietary fiber has anti-obesity effects (Wang et al.,2018). In this study (Xue et al., 2020a), *L. edodes* high molecular weight soluble dietary fiber (LEHSDF). Founded in this experiment, the main way to control body weight was the mechanism of LEHSDF and PL in the process of lipid digestion. After LEHSDF treatment, the maximum lipase can be inhibited to 81.89%. The reason may be that different concentrations of LEHSDF led to different degrees of reduction in the surface of lipid droplets exposed to enzymes, increased the inhibition rate (Benitez et al., 2019). When pH = 7.0, combined PL (0.05%) with LEHSDF sodium phosphate buffer at different concentrations, as the concentration increases, the ζ-potential also increased for LEHSDF-PL complex, which may be because LEHSDF gradually covered the surface of lipase (Ding et al., 2019), explain that the concentration of SDF affected the effect of LEHSDF and lipase. At the same time, possibly due to the interaction of hydrophobicity, electrostatic force, encapsulation and adsorption interactions, LEHSDF showed a strong inhibitory effect on pancreatic lipase. LEHSDF bound to PL, at position closed to tryptophan, the conformation of lipase was also changed. In addition, after treatment with LEHSDF, the lipid accumulation of HepG2 cells was alleviated, and the morphology and most functions of hepatocytes were preserved in a dose-dependent manner, indicated that LEHSDF had hypolipidemic potential.

Cordyceps sinensis polysaccharide (CSP) is a soluble dietary fiber with anti-obesity and anti-disease effects. The effects of CSP were analyzed by feeding mice (Chen et al., 2020). In this experiment, C57BL/6J mice was divided into three groups: The control group ate a normal diet and the group grew on a high-fat diet (HFD group), one group received additional CSP on the basis of HFD group (HFD+CSP group). Experiments had showed that CSP had a potential anti-obesity effect. In terms of body weight, cell diameter of adipocytes and accumulation of weight of epididy-mal fat, most of the mice in the HFD group were higher than those in the HFD+CSP group. However, CSP had side effects. The HFD+CSP group developed symptoms of nonalcoholic steato hepatiti (NASH), the hazard of NASH was very serious, and it was prone to steatosis, which led to lipid deposition, and finally liver cirrhosis and fibrosis (Bissoondial et al., 2020). The reason for the occurrence of NASH disease in this experiment is that the degradation of Actinobacteria leads to the aggravation of its high abundance in the induction of CSP, which further caused the appearance of NASH symptoms. Therefore purified fibers should be used with caution in the treatment of diseases.

3.3 Effects of edible fungi soluble dietary fiber on gut microbiota

SDS of edible fungi can regulate the growth of intestinal flora. Xue et al. (2020b) investigated the changes of three soluble dietary fibers from *Lentinula edodes* by-products (LESDF) with different molecular weights in the digestive system and their effects on gut microbiota (Table 3). Short-chain fatty acids (SCFAS) produced by LESDF during fermentation, and acetic acids and propionic acids were the main short-chain fatty acids, followed by butyric acid. LESDF was one of the important components with the effect on the composition and relative abundance of intestinal microbial community. This was similar to the reports of other researchers who have evaluated the effect polysaccharides

Table 2. The effect of different fibers (concentration 2%) on GDRI.

fiber	Incubation time (min)					
	30	60	90	120	180	300
Wood ear mushroom	34.80	35.50	31.14	31.30	28.20	22.80
Psyllium	30.76	37.00	34.60	34.40	27.30	21.70
Oat	6.66	11.50	12.25	7.40	7.80	5.60
Cellulose	17.37	13.20	9.54	7.20	6.50	3.00

Note: The data in this table came from the work of Wu et al. (2014).

Table 3. The production of SCFAS at 12 hours and 24 hours of fermentation on LESDF

Samples	time(h)	SCFAs concentrations (mM)				
		Ethanol concentration	Acetic acid	Propionic acid	Isobutyric acid	Butyric acid
Control	12	0%	23.14 ± 0.60	21.74 ± 0.23	1.96 ± 0.22	18.39 ± 0.41
LESDF-1		30%	29.14 ± 0.55	40.35 ± 0.49	2.95 ± 0.26	21.96 ± 0.11
LESDF-2		60%	41.43 ± 0.53	40.58 ± 0.24	4.21 ± 0.24	24.49 ± 0.27
LESDF-3		90%	56.00 ± 1.19	40.60 ± 0.08	9.80 ± 0.03	17.28 ± 0.05
Control	24	0%	19.61 ± 0.07	22.73 ± 0.28	6.61 ± 0.16	5.22 ± 0.08
LESDF-1		30%	34.95 ± 0.65	50.67 ± 0.96	4.83 ± 0.22	23.85 ± 0.55
LESDF-2		60%	36.27 ± 0.62	55.29 ± 0.46	7.04 ± 0.01	29.26 ± 0.38
LESDF-3		90%	20.51 ± 0.28	39.52 ± 0.62	9.95 ± 0.18	4.95 ± 0.03

Note: The data in this table came from the work of Xue et al. (2020b).

isolated from *Cordyceps Sinensis* on the gut microbiota in mice fed a high-fat diet (Chen et al., 2018).

The composition of the gut microbiota can play a role in improving the cognitive function of the brain through the gut-brain axis. β-glucans are one of the important components of SDF in edible fungi. β-glucans from *L. edodes* had also showed the potential to modulated the gut microbiota, thereby ameliorated cognitive impairment induced by high fat (HF) fed mice via the gut-brain axis (Pan et al., 2021). Using C57BL/6J mice, both long-term and short-term experiments showed that *L. edodes* β-glucans alleviated HF-induced intestinal dysbiosis in mice. In long-term experiments, colonic capacity of HF mice was enhanced by *L. edodes* β-glucans treatment. HF causes micro-gliosis and inflammation of nerves, whereas *L. edodes* β-glucans significantly attenuated it, and synaptic damage was alleviated in mice. These conditions suggested that *L. edodes* β-glucans can affected brain function by modulating gut microbes.

3.4 Anticancer potential of soluble dietary fiber from edible fungi

Soluble β-glucans extracted from *Sparassis crispa* (SC-SG) can regulate the functional activation of macrophages (Lee et al., 2010). Macrophages attacked cancer cells by releasing nitric oxide (NO), reactive oxygen species (ROS) and other substances. The production of NO in RAW264.7 cells in macrophages was greatly increased at 500 μg/mL Sc-SG, and the inducible NO synthase (iNOS) of RAW264 was enhanced under the condition of SC-SG. SC-SG-induced NO production verified the inhibitory effect of mitogen-activated protein kinase (MAPK) inhibitors on the activation of AP-1, PI3K/Akt and NF-κB due to IKK inhibitor activation, and it was found that MAPK inhibitors strongly inhibit the production of NO. AP-1, c-Jun and c-Fos are transcription factors activated by MAPK they were phosphorylated and translocated upon Sc-SG treatment. It showed that Sc-SG can promoted the production of NO, and the reason may be because of MAPK. Therefore, SC-SG had anticancer potential.

In another experiment, a soluble β-glucans was extracted from *Grifola frondosa*, named GFPS, which had a high molecular mass indicated high biological activity (Cui et al., 2020). Compared with other structures, it had a more stable triple helix structure. GFPS can form a stable complex with poly[A] (a kind of homonucleotides), which can better interacted with oligonucleotide. And the complex of GPFS and oligonucleotide was conducted through dectin-1. RAW264.7-dectin-1 cells produced TNFα under the induction of LPS, but the GFPS/TNF-A60 complex could alleviated this phenomenon. These results suggested that GFPS had anti-inflammatory, anticancer potential, but further research was needed.

4 The application of mushroom soluble dietary fiber

4.1 Application of SDF from edible fungi in food

Soluble dietary fiber, as a new type of dietary fiber and thickener, bulking agent, formulation aid, filler, etc., is mainly used in low-energy, high-fiber and other functional foods. Xue et al. (2019a) observed that addition of *Lentinus edodes* SDF with medium molecular weight and high branching degree played an important role in improving dough elasticity. Different apparent viscosity of *Lentinus edodes* SDF enrich the application in flour food processing.

Pleurotus ostreatus is an edible fungus rich in β-glucans. The soluble β-glucans extracted from *Pleurotus ostreatus* can act as an emulsifier to made emulsion, among them, maltodextrin and sunflower oil were used as the wall material and model of the emulsion, respectively. When the ratio of β-glucans to maltodextrin and sunflower oil are greater than 500 and 0.014, respectively, stable emulsions can be obtained, it showed that β-glucans from *Pleurotus ostreatus* can be an alternative to common emulsifiers, making them healthier (Gallotti et al., 2021).

Lactobacillus plantarum was a probiotic that can reach the human gut and strengthen the human immune systemand, and the potential of detoxifying Aflatoxin b_1 and inhibits its potent teratogenic carcinogenicity and mutagenicity (Jin et al., 2018; Vasconcelos et al., 2021; Gonçalves et al., 2022). Microcapsules were prepared by using *L. edodes* soluble dietary fiber (LESDF) as the coated material of Lactobacillus plantarum LP90 and alginate-calcium(a carrier widely used to target specific drugs on the colon) (Layek & Mandal, 2020) as the matrix (Xue et al., 2021). LESDF has low hygroscopicity and excellent stability (Bakry et al., 2019. Stability of LESDF was significantly higher than that of non-SDF, which may be because the LESDF layer formed on the surface stabilized the interior of the capsule to maintain pH neutrality (Arenales-Sierra et al., 2019). Therefore, the alginate-calcium microcapsules encapsulated with LESDF had excellent commercial application prospects.

4.2 Application of SDF from edible fungi in medicine

In recent years, soluble dietary fiber from edible fungi has been widely used in scientific research in the field of medicine and has considerable medical potential. In terms of lowering blood sugar, the viscous dietary fiber extracted from *Auricularia polytricha* was tested in vitro and the β-glucans extracted from *Pleurotus sajor-caju* were tested in mice vivo, and both performed very well in relieving hyperglycemia, and can be combined with drugs in medical treatment to relieve blood sugar in diabetic patients. The β-glucans extracted from *Sparassis crispa* achieved anticancer effects by affecting RAW264 cells, and the β-glucans extracted from *Grifola frondosa* introduced oligonucleotides through dectin-1, both of which showed excellent anticancer prospects (Wu et al., 2014; Kanagasabapathy et al., 2012; Lee et al., 2010; Cui et al., 2020).

While the soluble dietary fibers of different molecular weights were extracted from *L. edodes* by stepwise ethanol extraction, high molecular weight SDF showed excellent anti-obesity, and by adjusting different molecular weight SDFs, the intestinal flora could be in coordinated state, which has application prospects for the treatment of gastrointestinal diseases. And β-glucans, also extracted from *L. edodes*, can treat cognitive dysfunction in the brain by adjusting the intestinal flora. Therefore, adjusting the gut flora is a way to keep the body healthy, not just to treat gastrointestinal problems, and edible mushroom soluble dietary fiber is a great choice. However, *Cordyceps sinensis* polysaccharide caused NASH while achieving anti-obesity. Therefore, it should be used with great caution before the research on the purified fibers of certain edible fungi is not deep enough (Xue et al., 2020a; Xue et al., 2020b; Pan et al., 2021; Chen et al., 2020).

5 Conclusions and future prospects

The research on the soluble dietary fiber of edible fungi has been carried out for a long time. On the basis of researches on physical chemistry and efficacy evaluation of mushroom SDF, more and more people try to convert IDF into SDF to increase the content of SDF and change its overall physical and chemical properties. Most of the transformation principle is to break covalent and non-covalent bonds in carbohydrate and protein moieties (Bader Ul Ain et al., 2019a). However, the extraction methods such as physical and chemical methods have problems such as low purity of SDF, chemical residues, and environmental pollution. Therefore, according to the processing characteristics of different edible fungi, optimizing the efficient and environmentally friendly extraction method is one of the important research directions of edible fungi SDF. In addition, the SDF of edible fungi is generally beneficial to the human intestinal tract in research, and has anti-obesity, hypolipidemic and other effects, but attention should also be paid to the potential harm caused by purified fiber.

In short, edible mushroom as a source of SDF has not been fully utilized. Since there are many varieties of edible fungi that have not been studied, it is expected to develop more new methods for preparing mushroom SDF and high-SDF products rich in mushroom SDF in the future. This will greatly promote the application of mushroom SDF as a functional food ingredient or product in the future and provide various health benefits for human beings.

Acknowledgements

This work was supported by funding from Fujian provincial department of science and technology, China [2020R1032003, 2020R1032004, 2021R10320011 and 2021R1032008], and Fujian Academy of Agricultural Sciences [YC20210007 and CXTD2021018-2]. Also, thank you for being supported by the “5511” collaborative innovation project of Fujian province and the Chinese Academy of Agricultural Sciences on the high-quality development and transcendence of agriculture (XTCXGC2021014), Fujian province modern edible fungus industry technology system construction project (Mincaizhi [2019] No. 897).

References

Abreu Y Abreu, A. T., Milke-García, M. P., Argüello-Arévalo, G. A., Calderón-de la Barca, A. M., Carmona-Sánchez, R. I., Consuelo-Sánchez, A., Coss-Adame, E., García-Cedillo, M. F., Hernández-Rosiles, V., Icaza-Chávez, M. E., Martínez-Medina, J. N., Morán-Ramos, S., Ochoa-Ortiz, E., Reyes-Apodaca, M., Rivera-Flores, R. L., Zamarripa-Dorsey, F., Zárate-Mondragón, F., & Vázquez-Frias, R. (2021). Dietary fiber and the microbiota: a narrative review by a group of experts from the Asociación Mexicana de Gastroenterología. *Revista de gastroenterologia de Mexico (English)*, 86(3), 287-304. http://dx.doi.org/10.1016/j.rgmx.2021.02.004. PMid:34144942.

Alyassin, M., & Campbell, G. M. (2019). Challenges and constraints in analysis of oligosaccharides and other fibre components. In G. González-Ortiz, M. R. Bedford, K. E. Bach Knudsen, C. M. Courtin and H. L. Classen (Eds.), *The value of fibre: engaging the second brain for animal nutrition* (Chap. 15, pp. 257-277). The Netherlands: Wageningen Academic Publishers.

Arenales-Sierra, I. M., Lobato-Calleros, C., Vernon-Carter, E. J., Hern'andez-Rodríguez, L., & Alvarez-Ramirez, J. (2019). Calcium alginate beads loaded with $Mg(OH)_2$ improve L. casei viability under simulated gastric condition. *Lebensmittel-Wissenschaft + Technologie*, 112, 108220. http://dx.doi.org/10.1016/j.lwt.2019.05.118.

Bader Ul Ain, H., Saeed, F., Ahmed, A., Asif Khan, M., Niaz, B., & Tufail, T. (2019a). Improving the physicochemical properties of partially enhanced soluble dietary fiber through innovative techniques: a coherent review. *Journal of Food Processing and Preservation*, 43(4), e13917. http://dx.doi.org/10.1111/jfpp.13917.

Bader Ul Ain, H., Saeed, F., Khan, M. A., Niaz, B., Khan, S. G., Anjum, F. M., Tufail, T., & Hussain, S. (2019b). Comparative study of chemical treatments in combination with extrusion for the partial conversion of wheat and sorghum insoluble fiber into soluble. *Food Science & Nutrition*, 7(6), 2059-2067. http://dx.doi.org/10.1002/fsn3.1041. PMid:31289654.

Bai, Q., Xu, J., Zhu, W., Huang, C., Ni, X., Zhao, H., Feng, X., Li, L., Du, S., Fan, R., & Wang, J. (2021). Effects of consumption of a low glycaemic index formula on glycaemic control in patients with type 2 diabetes managed by medical nutrition therapy. *Food Science and Technology (Campinas)*, 41(3), 768-774. http://dx.doi.org/10.1590/fst.51320.

Bakry, A. M., Huang, J., Zhai, Y., & Huang, Q. (2019). Myofibrillar protein with κ- or λ-carrageenans as novel shell materials for microencapsulation of tuna oil through complex coacervation. *Food Hydrocolloids*, 96, 43-53. http://dx.doi.org/10.1016/j.foodhyd.2019.04.070.

Benitez, V., Rebollo-hernanz, M., Hernanz, S., Chantres, S., Aguilera, Y., & Martin-Cabrejas, M. A. (2019). Coffee parchment as a new dietary fiber ingredient: Functional and physiological characterization. *Food Research International*, 122, 105-113. http://dx.doi.org/10.1016/j.foodres.2019.04.002. PMid:31229061.

Bissoondial, T. L., Han, Y., Mullan, S., Pabla, A. K., Spahn, K., Shi, S., Zheng, L., Zhou, P., Jiang, K., Prakash, N., Bhutkar, S., Ali, Q., Li, J., Hu, Z., Pellicano, A. J., Goldberg, I. D., & Narayan, P. (2020). Liver biopsy hydroxyproline content is a diagnostic for hepatocellular carcinoma in murine models of nonalcoholic steatohepatitis. *Diagnostics (Basel)*, 10(10), 784. http://dx.doi.org/10.3390/diagnostics10100784. PMid:33020436.

Brennan, C. S., & Cleary, L. J. (2005). The potential use of cereal (1→3,1→4)-β-d-glucans as functional food ingredients. *Journal of Cereal Science*, 42(1), 1-13. http://dx.doi.org/10.1016/j.jcs.2005.01.002.

Brennan, M. A., Derbyshire, E., Tiwari, B. K., & Brennan, C. S. (2012). Enrichment of extruded snack products with coproducts from chestnut mushroom (*Agrocybe aegerita*) production: interactions between dietary fiber, physicochemical characteristics, and glycemic load. *Journal of Agricultural and Food Chemistry*, 60(17), 4396-4401. http://dx.doi.org/10.1021/jf3008635. PMid:22458938.

Chawla, R., & Patil, G. R. (2010). Soluble Dietary Fiber. *Comprehensive Reviews in Food Science and Food Safety*, 9(2), 178-196. http://dx.doi.org/10.1111/j.1541-4337.2009.00099.x.

Chen, L., Xu, W., Chen, D., Chen, G., Liu, J., Zeng, X., Shao, R., & Zhu, H. (2018). Digestibility of sulfated polysaccharide from the brown seaweed Ascophyllum nodosum and its effect on the human gut microbiota in vitro. *International Journal of Biological Macromolecules*, 112, 1055-1061. http://dx.doi.org/10.1016/j.ijbiomac.2018.01.183. PMid:29425873.

Chen, L., Zhang, L., Wang, W., Qiu, W., Liu, L., Ning, A., Cao, J., Huang, M., & Zhong, M. (2020). Polysaccharides isolated from *Cordyceps Sinensis* contribute to the progression of NASH by modifying the gut microbiota in mice fed a high-fat diet. *PLoS One*, 15(6), e0232972. http://dx.doi.org/10.1371/journal.pone.0232972. PMid:32512581.

Cui, H., Zhu, X., Huo, Z., Liao, B., Huang, J., Wang, Z., Song, C., Hu, X., & Fang, J. (2020). A beta-glucan from Grifola frondosa effectively delivers therapeutic oligonucleotide into cells via dectin-1 receptor and attenuates TNFalpha gene expression. *International Journal of Biological Macromolecules*, 149, 801-808. http://dx.doi.org/10.1016/j.ijbiomac.2020.01.236. PMid:31982530.

Ding, L., Huang, Y., Cai, X., & Wang, S. (2019). Impact of pH, ionic strength and chitosan charge density on chitosan / casein complexation and phase behavior. *Carbohydrate Polymers*, 208, 133-141. http://dx.doi.org/10.1016/j.carbpol.2018.12.015. PMid:30658783.

Duque, A., Manzanares, P., & Ballesteros, M. (2017). Extrusion as a pretreatment for lignocellulosic biomass: Fundamentals and applications. *Renewable Energy*, 114, 1427-1441. http://dx.doi.org/10.1016/j.renene.2017.06.050.

Gallotti, F., Turchiuli, C., & Lavelli, V. (2021). Production of stable emulsions using β-glucans extracted from *Pleurotus ostreatus* to encapsulate oxidizable compounds. *Journal of Food Process Engineering*, 2021, e13949. http://dx.doi.org/10.1111/jfpe.13949.

Gao, W., Chen, F., Wang, X., & Meng, Q. (2020). Recent advances in processing food powders by using superfine grinding techniques: a review. *Comprehensive Reviews in Food Science and Food Safety*, 19(4), 2222-2255. http://dx.doi.org/10.1111/1541-4337.12580. PMid:33337081.

Gonçalves, B. L., Uliana, R. D., Coppa, C. F. S. C., Lee, S. H. I., Kamimura, E. S., Oliveira, C. A. F., & Corassin, C. H. (2022). Aflatoxin M1: biological decontamination methods in milk and cheese. *Food Science and Technology (Campinas)*, 42, e22920. https://doi.org/10.1590/fst.22920.

Gunness, P., & Gidley, M. J. (2010). Mechanisms underlying the cholesterol-lowering properties of soluble dietary fibre polysaccharides. *Food & Function*, 1(2), 149-155. http://dx.doi.org/10.1039/c0fo00080a. PMid:21776465.

Hua, L. Y., Ning, Z., & Yuebao, N. (2022). Determination of SOD in black ginger extract and its effect on the liver of rats with type 2 diabetes. *Food Science and Technology (Campinas)*, 42, 42. http://dx.doi.org/10.1590/fst.115021.

Iaccarino, N., Khakimov, B., Mikkelsen, M. S., Nielsen, T. S., Jensen, M. G., Randazzo, A., & Engelsen, S. B. (2020). Structurally different mixed linkage beta-glucan supplements differentially increase secondary bile acid excretion in hypercholesterolaemic rat faeces. *Food & Function*, 11(1), 514-523. http://dx.doi.org/10.1039/C8FO02507J. PMid:31833481.

Jia, F., Liu, X., Gong, Z., Cui, W., Wang, Y., & Wang, W. (2020a). Extraction, modification, and property characterization of dietary fiber from *Agrocybe cylindracea. Food Science & Nutrition*, 8(11), 6131-6143. http://dx.doi.org/10.1002/fsn3.1905. PMid:33282264.

Jia, F., Yang, S., Ma, Y., Gong, Z., Cui, W., Wang, Y., & Wang, W. (2020b). Extraction optimization and constipation-relieving activity of dietary fiber from *Auricularia polytricha. Food Bioscience*, 33, 33. http://dx.doi.org/10.1016/j.fbio.2019.100506.

Jin, Y. J., Park, Y. K., Cho, M. S., Lee, E. S., & Park, D. S. (2018). New insight and metrics to understand the ontogeny and succession of Lactobacillus plantarum subsp. plantarum and Lactobacillus plantarum subsp argentoratensis. *Scientific Reports*, 8(1), 6029. http://dx.doi.org/10.1038/s41598-018-24541-6. PMid:29662105.

Jovanovski, E., Khayyat, R., Zurbau, A., Komishon, A., Mazhar, N., Sievenpiper, J. L., Blanco Mejia, S., Ho, H. V. T., Li, D., Jenkins, A. L., Duvnjak, L., & Vuksan, V. (2019). Should viscous fiber supplements be considered in diabetes control? results from a systematic review and meta-analysis of randomized controlled trials. *Diabetes Care*, 42(5), 755-766. http://dx.doi.org/10.2337/dc18-1126. PMid:30617143.

Kanagasabapathy, G., Kuppusamy, U. R., Abd Malek, S. N., Abdulla, M. A., Chua, K. H., & Sabaratnam, V. (2012). Glucan-rich polysaccharides from *Pleurotus sajor-caju* (Fr.) Singer prevents glucose intolerance, insulin resistance and inflammation in C57BL/6J mice fed a high-fat diet. *BMC Complementary and Alternative Medicine*, 12(1), 261. http://dx.doi.org/10.1186/1472-6882-12-261. PMid:23259700.

Khan, M. A., Amir, R. M., Ameer, K., Rakha, A., Faiz, F., Hayat, I., Nadeem, M., Ahmed, Z., Riaz, A., & Ashraf, I. (2021). Characterization of oat bran beta-glucan with special reference to efficacy study to elucidate its health claims for diabetic patients. *Food Science and Technology (Campinas)*, 41(1), 105-112. http://dx.doi.org/10.1590/fst.39019.

Layek, B., & Mandal, S. (2020). Natural polysaccharides for controlled delivery of oral therapeutics: a recent update. *Carbohydrate Polymers*, 230, 115617. http://dx.doi.org/10.1016/j.carbpol.2019.115617. PMid:31887888.

Lee, S. Y., Lee, Y. G., Byeon, S. E., Han, S., Choi, S. S., Kim, A. R., Lee, J., Lee, S. J., Hong, S., & Cho, J. Y. (2010). Mitogen activated protein kinases are prime signalling enzymes in nitric oxide production induced by soluble beta-glucan from *Sparassis crispa. Archives of Pharmacal Research*, 33(11), 1753-1760. http://dx.doi.org/10.1007/s12272-010-1107-3. PMid:21116778.

Lu, X., Brennan, M. A., Serventi, L., Liu, J., Guan, W., & Brennan, C. S. (2018). Addition of mushroom powder to pasta enhances the antioxidant content and modulates the predictive glycaemic response of pasta. *Food Chemistry*, 264, 199-209. http://dx.doi.org/10.1016/j.foodchem.2018.04.130. PMid:29853366.

Lv, G., Zhang, Z., Pan, H., & Fan, L. (2014). Effect of Physical Modification of Mushroom (A. chaxingu) Powders on their Physical and Chemical Properties. *Food Science and Technology Research*, 20(4), 731-738. http://dx.doi.org/10.3136/fstr.20.731.

Matsuura, N., Zang, L., Nishimura, N., & Shimada, Y. (2020). Lacto-Fermented Cauliflower Fungus (*Sparassis crispa*) Ameliorates Hepatic Steatosis by Activating Beta-Oxidation in Diet-Induced Obese Zebrafish. *Journal of Medicinal Food*, 23(8), 803-810. http://dx.doi.org/10.1089/jmf.2019.4571. PMid:32466711.

Ming, J., Chen, L., Hong, H., & Li, J. (2015). Effect of superfine grinding on the physico-chemical, morphological and thermogravimetric properties of *Lentinus edodes* mushroom powders. *Journal of the Science of Food and Agriculture*, 95(12), 2431-2437. http://dx.doi.org/10.1002/jsfa.6967. PMid:25345361.

Nile, S. H., & Park, S. W. (2014). Total, Soluble, and Insoluble Dietary Fibre Contents of Wild Growing Edible Mushrooms. *Czech Journal of Food Sciences*, 32(3), 302-307. http://dx.doi.org/10.17221/226/2013-CJFS.

Pan, W., Jiang, P., Zhao, J., Shi, H., Zhang, P., Yang, X., Biazik, J., Hu, M., Hua, H., Ge, X., Huang, X. F., & Yu, Y. (2021). β-Glucan from Lentinula edodes prevents cognitive impairments in high-fat diet-induced obese mice: involvement of colon-brain axis. *Journal of Translational Medicine*, 19(1), 54. http://dx.doi.org/10.1186/s12967-021-02724-6. PMid:33541370.

Pastell, H., Putkonen, T., & Rita, H. (2019). Dietary fibre in legumes, seeds, vegetables, fruits and mushrooms: Comparing traditional and semi-automated filtration techniques. *Journal of Food Composition and Analysis*, 75, 1-7. http://dx.doi.org/10.1016/j.jfca.2018.09.011.

Qi, J., Li, Y., Masamba, K. G., Shoemaker, C. F., Zhong, F., Majeed, H., & Ma, J. (2016). The effect of chemical treatment on the In vitro hypoglycemic properties of rice bran insoluble dietary fiber. *Food Hydrocolloids*, 52, 699-706. http://dx.doi.org/10.1016/j.foodhyd.2015.08.008.

Ryoo, R., Sou, H.-D., Ka, K.-H., & Park, H. (2018). Elicitor-induced β-glucan contents in fruit body of cauliflower mushroom (*Sparassis latifolia*). *Forest Science and Technology*, 14(3), 119-125. http://dx.doi.org/10.1080/21580103.2018.1475307.

Sánchez-Madrigal, M. Á., Neder-Suárez, D., Quintero-Ramos, A., Ruiz-Gutiérrez, M. G., Meléndez-Pizarro, C. O., Piñón-Castillo, H. A., Galicia-García, T., & Ramírez-Wong, B. (2015). Physicochemical properties of frozen tortillas from nixtamalized maize flours enriched with β-glucans. *Food Science and Technology (Campinas)*, 35(3), 552-560. http://dx.doi.org/10.1590/1678-457X.6715.

Stephen, A. M., Champ, M. M., Cloran, S. J., Fleith, M., van Lieshout, L., Mejborn, H., & Burley, V. J. (2017). Dietary fibre in europe: current state of knowledge on definitions, sources, recommendations, intakes and relationships to health. *Nutrition Research Reviews*, 30(2), 149-190. http://dx.doi.org/10.1017/S095442241700004X. PMid:28676135.

Subiria-Cueto, R., Coria-Oliveros, A. J., Wall-Medrano, A., Rodrigo-García, J., González-Aguilar, G. A., Martinez-Ruiz, N. R., & Alvarez-Parrilla, E. (2022). Antioxidant dietary fiber-based bakery products: a new alternative for using plant-by-products. *Food Science and Technology (Campinas)*, 42, 42. http://dx.doi.org/10.1590/fst.57520.

Tian, M., Li, D., Ma, C., Feng, Y., Hu, X., & Chen, F. (2021). Barley Leaf Insoluble Dietary Fiber Alleviated Dextran Sulfate Sodium-Induced Mice Colitis by Modulating Gut Microbiota. *Nutrients*, 13(3), 846. http://dx.doi.org/10.3390/nu13030846. PMid:33807544.

Tobaruela, E. C., Santos, A. O., Almeida-Muradian, L. B., Araujo, E. D. S., Lajolo, F. M., & Menezes, E. W. (2018). Application of dietary fiber method AOAC 2011.25 in fruit and comparison with AOAC 991.43 method. *Food Chemistry*, 238, 87-93. http://dx.doi.org/10.1016/j.foodchem.2016.12.068. PMid:28867106.

Vasconcelos, R. A. M., Kalschne, D. L., Wochner, K. F., Moreira, M. C. C., Becker-Algeri, T. A., Centenaro, A. I., et al (2021). Feasibility of L. plantarum and prebiotics on Aflatoxin B1 detoxification in cow milk. *Food Science and Technology (Campinas)*, 41, 627-632.

Wang, H., Hong, T., Li, N., Zang, B., & Wu, X. (2018). Soluble dietary fiber improves energy homeostasis in obese mice by remodeling the gut microbiota. *Biochemical and Biophysical Research Communications*, 498(1), 146-151. http://dx.doi.org/10.1016/j.bbrc.2018.02.017. PMid:29462619.

Westenbrink, S., Brunt, K., & van der Kamp, J. W. (2013). Dietary fibre: challenges in production and use of food composition data. *Food Chemistry*, 140(3), 562-567. http://dx.doi.org/10.1016/j.foodchem.2012.09.029. PMid:23601407.

Wu, N. J., Chiou, F. J., Weng, Y. M., Yu, Z. R., & Wang, B. J. (2014). In vitro hypoglycemic effects of hot water extract from *Auricularia polytricha* (wood ear mushroom). *International Journal of Food Sciences and Nutrition*, 65(4), 502-506. http://dx.doi.org/10.3109/09637486.2014.886183. PMid:24524622.

Xiang, H., Sun-Waterhouse, D., & Cui, C. (2021). Hypoglycemic polysaccharides from *Auricularia auricula* and Auricularia polytricha inhibit oxidative stress, NF-κB signaling and proinflammatory cytokine production in streptozotocin-induced diabetic mice. *Food Science and Human Wellness*, 10(1), 87-93. http://dx.doi.org/10.1016/j.fshw.2020.06.001.

Xue, Z., Chen, Y., Jia, Y., Wang, Y., Lu, Y., Chen, H., & Zhang, M. (2019a). Structure, thermal and rheological properties of different soluble dietary fiber fractions from mushroom *Lentinula edodes* (Berk.) Pegler residues. *Food Hydrocolloids*, 95, 10-18. http://dx.doi.org/10.1016/j.foodhyd.2019.04.015.

Xue, Z., Ma, Q., Guo, Q., Santhanam, R. K., Gao, X., Chen, Z., Wang, C., & Chen, H.. (2019b). Physicochemical and functional properties of extruded dietary fiber from mushroom *Lentinula edodes* residues. *Food Bioscience*, 32, 32. http://dx.doi.org/10.1016/j.fbio.2019.100452.

Xue, Z., Gao, X., Jia, Y., Wang, Y., Lu, Y., Zhang, M., Panichayupakaranant, P., & Chen, H. (2020a). Structure characterization of high molecular weight soluble dietary fiber from mushroom *Lentinula edodes* (Berk.) Pegler and its interaction mechanism with pancreatic lipase and bile salts. *International Journal of Biological Macromolecules*, 153, 1281-1290. http://dx.doi.org/10.1016/j.ijbiomac.2019.10.263. PMid:31758996.

Xue, Z., Ma, Q., Chen, Y., Lu, Y., Wang, Y., Jia, Y., Zhang, M., & Chen, H. (2020b). Structure characterization of soluble dietary fiber fractions from mushroom *Lentinula edodes* (Berk.) Pegler and the effects on fermentation and human gut microbiota in vitro. *Food Research International*, 129, 108870. http://dx.doi.org/10.1016/j.foodres.2019.108870. PMid:32036882.

Xue, Z., Chen, Z., Gao, X., Zhang, M., Panichayupakaranant, P., & Chen, H. (2021). Functional protection of different structure soluble dietary fibers from *Lentinus* edodes as effective delivery substrate for Lactobacillus plantarum LP90. *Lwt*, 136(Pt 2), 110339. https://doi.org/10.1016/j.lwt.2020.110339.

Yang, J., Xiao, A., & Wang, C. (2014). Novel development and characterisation of dietary fibre from yellow soybean hulls. *Food Chemistry*, 161, 367-375. http://dx.doi.org/10.1016/j.foodchem.2014.04.030. PMid:24837964.

Yu, K., Ke, M. Y., Li, W. H., Zhang, S. Q., & Fang, X. C. (2014). The impact of soluble dietary fibre on gastric emptying, postprandial blood glucose and insulin in patients with type 2 diabetes. *Asia Pacific Journal of Clinical Nutrition*, 23(2), 210-218. PMid:24901089.

Zhang, Z., Song, H., Peng, Z., Luo, Q., Ming, J., & Zhao, G. (2012). Characterization of stipe and cap powders of mushroom (*Lentinus edodes*) prepared by different grinding methods. *Journal of Food Engineering*, 109(3), 406-413. http://dx.doi.org/10.1016/j.jfoodeng.2011.11.007.

Zhou, T., Wang, M., Ma, H., Li, X., Heianza, Y., & Qi, L. (2021). Dietary fiber, genetic variations of gut microbiota-derived short-chain fatty acids, and bone health in UK biobank. *The Journal of Clinical Endocrinology and Metabolism*, 106(1), 201-210. http://dx.doi.org/10.1210/clinem/dgaa740. PMid:33051670.