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Research Article

Physicochemical and Antioxidant Properties of Spray Drying Powders from *Stropharia rugoso-annulata* and *Agaricus brunnescens* Blanching Liquid

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Abstract: This study investigated the impacts of carrier agents on the physicochemical properties and antioxidant retention rate of spray drying powders from blanching liquids of *Stropharia rugoso-annulata* (BLS) and *Agaricus brunnescens* (BLA). Physicochemical, nutritional and antioxidant properties of the powder were examined in order to better determine potential applications of powders. Carrier agents could improve the qualities of the spray drying BLS powders and BLA powders and *β*-Cyclodextrin (*β*-CD) was more suitable as carrier agent than Maltodextrin (MD). The powder had higher flour yield and antioxidant retention rate while *β*-CD addition rate was 44.44 g/100 g (w/w).Proximate composition and total phenolics were performed. The powder was ranging from 5 and 30 μm in particle size with spherical particle morphology. BLA powders had higher antioxidant activity (hydroxyl radical scavenging capacity and lipid peroxidation inhibition ability) than BLS powder.

Keywords: Antioxidant activity, blanching liquid, nutrition, physicochemical properties, spray drying

INTRODUCTION

Stropharia rugoso-annulata Farl: Murrill and *Agaricus brunnescens* Peck are edible fungi from two genuses, which have been worldwide cultivated especially in China. Both mushrooms are favorable due to their unique flavor and high quality in nutritional value. They are also used in processing for canned food and instant products.

Blanching is essential for mush room processing. This procedure may dissolve some soluble nutrients from mushroom fruit bodies including protein and carbohydrates (Chen *et al*., 2014). The blanching liquid is traditionally discarded as bio-waste although it contains certain amount of soluble nutrients. The discarding may result not only in environment pollution but also in loss of valuable mushroom nutrients. Therefore, it is important in studying process technology for use of blanching nutrients from edible fungi.

Spray drying process is considered a conventional method to convert liquids to powders and is used in the wide range of products in food industries to produce dry powders (Samaneh *et al*., 2015; Fang and Bhandari, 2011; Phisut, 2012). However, the high viscous nature and flow problems of the feed will result in deposition of the powder on the dryer wall and conveying system (Tonon *et al*., 2008; Bhandari and Howes, 2005). Recently, the addition of carrier agents has proved to be an effective way to ease this technological problem. Meanwhile, the carrier agents protect sensitive food components such as flavour, colour and bioactive compounds against unfavourable environmental conditions (Ferrari *et al*., 2012a; Martha *et al*., 2014). Although spray drying is the most commonly used encapsulation method in the food industry, the report on applying spray drying techniques for processing of mushroom blanching liquid is considerably few.

The physicochemical properties and nutritional quality of spray drying powder are factors affecting the application of the powder further in food industry (Maruf *et al*., 2010; Ng *et al*., 2012). For better application of spray drying powders in different food processing, parameters about physicochemical properties, nutrient composition and functionality of these powders are required.

In this study, the effects of *β*-Cyclodextrin (*β*-CD) and Maltodextrin (MD) on the physicochemical properties and antioxidant capacity of spray drying powders from blanching liquids of *Stropharia rugoso-annulata* and *Agaricus brunnescens* have been investigated. Physicochemical properties, nutritional composition and antioxidant capacity of the powders were determined. The study can take full advantage of mushroom blanching liquid waste resources and reduce pollution; the resultant spray drying powders will potentially be used as functional food ingredients.

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MATERIALS AND METHODS

Material preparation: Blanching liquids of *Stropharia rugoso-annulata* (BLS) were collected from mushroom processing manufacture in Jiangle County, Fujian province, China, whilst blanching liquids of *Agaricus brunnescens* (BLA) were supplied by Fujian Dachun mushroom Development Co., Ltd. China. The liquids were collected from *Stropharia rugoso-annulata* and *Agaricus brunnescens* blanching waste water, after 100°C boiling water processing for 5 min without adding any additives. BLS and BLA samples were stored at -20°C for further use.

β-CD was obtained from Shanghai Chemical Reagent Co., Ltd, China. MD (dextrose equivalence 20) was sourced from Xiwang Food Co., Shandong, China.

Spray drying: After carrier agents (β-CD or MD) mixing thoroughly, BLS and BLA samples were concentrated with rotary evaporator (Senco-GG17, Shanghai Shenke Science and Technology Co., Ltd.) at 55°C with 0.098 MPa to 10 g/100 g(w/w) solids content before spray drying. The spray drying was performed in a laboratory scale spray dryer (Shiyuan Mini Spray Dryer SY6000, China) under the following operational conditions: Solid content 10 g/100 g, inlet air temperature 150°C, outlet air temperature 85±5°C, atomization pressure 90MPa, feed flow rate 850 mL/h and blower rate 1.15m^3/min. The spray drying powders were packed with aluminum foil bag and storied at -20°C for further use.

Physicochemical properties of powder:

Flour yield: The yield of the powder was determined according to Chen *et al*. (2014) using following equation:

$$\text{Yield} = \frac{M\,(1-R)}{L} \times 100$$

where,

M = The mass of the powder
R = The moisture content of the powder
L = The total solid mass of the feed mixture, as determined from the solid content of the mixture after hot-air drying to constant weight at 105°C.

Bulk density: The bulk density of powder samples was determined according to Kha *et al*. (2010) with slight modifications. About 2 g of powder was weighed and transferred into a 50 mL measuring cylinder and held on a vortex vibrator for 1 min. The bulk density was determined as the ratio of mass of the powder and the volume occupied in the cylinder.

Dispersion time: The dispersion time of the powder was determined by pouring 10 g of the powder into a 250 mL beaker with 100 mL deionized water in 25°C water-baths. The time (s) was recorded immediately when the stirring began until all samples were dispersed (Quek *et al*., 2007).

Scanning electron microscopy: Morphological characteristics of the powders were observed using a JSM-6380LV scanning electron microscope (Japan).

Nutrient analysis:

Proximate composition: Moisture content of the spray drying powder was determined according to AOAC official method 945.15 (AOAC, 2012). Water activity (a_w) is detected by the smart water activity meter (Wuxi Huake Instrument Co., Ltd. China). Protein content was measured using Kjeldahl analysis using a protein factor of 6.25 according to AOAC Method 991.20.1(AOAC, 2012). Calcium, iron and zinc content were analyzed by the Central Lab, Fujian Academy of Agricultural Sciences, according to AOAC Official Method 984.27 (AOAC, 2012). Total sugar and reducing sugar were determined according to AOAC official method 974.06 and 945.66 (AOAC, 2012) respectively.

Total flavonoid content: Total phenolics were determined according to Singleton and Rossi (1965). Gallic acid was used as the reference standard and the results were expressed as mg gallicacid equivalents per 100 g of sample on a dry basis.

Determination of antioxidant activities

Hydroxyl radical scavenging capacity: The scavenging ability of hydroxyl radicals is measured by the method of Nur *et al*. (2013). The reaction mixture (1.0 mL) consist of 100 μL of 2-deoxy-Dribose (28 mM in 20 mM KH_2PO_4-KOH buffer, pH 7.4), 500 μL of the extract, 200 μL EDTA (1.04 mM) and 200 μM $FeCl_3$ (1:1 v/v), 100 μL of H_2O_2 (1.0 mM) and 100 μL ascorbic acid (1.0 mM) which is incubated at 37 for 1 h. One milliliter of thiobarbituric acid (1%) and 1.0 mL of trichloroacetic acid (2.8%) are added and incubated at 100°C for 20 min. After cooling, absorbance is measured at 532 nm, against a blank sample.

Lipid peroxidation inhibition ability: The determination of lipid peroxidation inhibition activity (LPI) was adapted using the procedure described by Serratosa *et al*. (2011). Concentration for 50% of maximal effect (EC_{50}) was obtained by interpolation from linear regression analysis and represented the effective concentration of powder (mg/mL) at which the Hydroxylradicals were scavenged by 50% and lipid peroxidation was inhibited by 50%, respectively.

Antioxidant retention rate: Antioxidant retention rate was to determine retention degree of hydroxyl radical scavenging capacity. Powder solution after reconstitution was formulated into the solution with same mass fraction of solids before spraying. The antioxidant retention rate of the powder was by the following equation:

Table 1: Effect of carrier agents on the BLS and BLA powder qualities (mean ± SD, n = 3)

	BLS powder			BLA powder		
Physico-chemical properties	Control	β-CD	Maltodextrin	Control	β-CD	Maltodextrin
Moisture content (g/100 g)	9.62±0.81[b]	3.98±0.25[a]	3.84±0.33[a]	7.64±0.98[b]	3.12±0.14[a]	3.35±0.21[a]
Flour yield (g/100 g)	13.97±2.31[b]	51.01±1.34[a]	53.34±1.52[a]	18.38±3.52[b]	48.65±1.56[a]	46.17±1.39[a]
Dispersion time(s)	146.33±9[c]	88.47±5.00[b]	76.21±6.00[a]	132.86±13[b]	85.37±5[a]	78.42±8[a]
Bulk density (g/mL)	0.31±0.02[b]	0.400±0.01[a]	0.440±0.01[a]	0.33±0.02[b]	0.43±0.01[a]	0.46±0.01[a]
Antioxidant retention rate (%)	51.65±0.77[c]	82.32±0.52[a]	62.84±0.42[b]	55.48±2.64[c]	85.79±1.53[a]	64.92±1.45[b]

1): Values are means ± SD (n = 3) and values in the same line bearing different superscript lowercase letters are significant difference ($p<0.05$) by Duncan's test; 2): Fixing the other process conditions (air temperature of 150°C, atomization pressure of 90 MPa, feed flow rate 850 mL/h, the total mass fraction of solids of 10%, the feed temperature 30°C); 3): β-CD and MD (20DE) represent the flours prepared with addition of 50 g/100 g β-CD, 50 g/100 g MD, and the control sample was the flour without addition of any carrier agent; 4): Moisture content was expressed on wet weight basis

$$\text{Antioxidan t retention rate} = \frac{A_2}{A_1} \times 100\,\%$$

where, A_1 is hydroxyl radical scavenging capacity of the mixed feed adding carrier agents, A_2 is hydroxyl radical scavenging capacity of the powder solution after reconstitution.

RESULTS AND DISCUSSION

Effects of carrier agents on the quality of BLS powders and BLA powders:

Moisture content and flour yield: Table 1 showed the effects of the addition of β-CD and MD on the qualities of spray dryingBLS powders and BLA powders. The additions of β-CD (50 g/100 g) and maltodextrin (50 g/100 g) significantly improved the yield of flour and moisture content. Moisture content is an important powder property, which is related to the drying efficiency. It is suggested that the addition of the carrier agents facilitated the loss of moisture in the process of drying. Similar results were also reported by Peng *et al*. (2013). In addition, our study found that the control sample easily absorbed moisture and difficultly preserved.

Dispersion time and bulk density: BLS powders and BLA powders produced with both carrier agents exhibited the shorter dispersion time and the higher bulk density, whereas without addition of any carrier agent resulted in significantly longer dispersion time and lower bulk density values (Table 1).

Antioxidant retention rate: Both carrier agents increased significantly antioxidant retention rate of BLS powders and BLA powders, but β-CD improved better (Table 1). This behavior was probably due to the differences between the chemical structures of both carrier agents, because β-CD is highly symmetrical, cylindrical three-dimensional structure and the glycosidic linkages in the molecule are co-planar. The hydrophilic groups are on the outside of the ring, while the hydrophobic groups are within the ring. And β-CD easily wraps blanching liquid antioxidant activity of substance, less destroyed by high temperatures.

Therefore, carrier agents can improve the quality of the spray drying BLS powders and BLA powders and β-CD is more suitable as carrier agents than MD.

Effects of the adding amount of β-CD on the quality of BLS powders and BLA powders:

Flour yield: The additions of β-CD (16.67-54.55 g/100 g (w/w)) significantly improved the yield of flour (Fig. 1A). With the increase in the addition of β-CD, the flour yield of BLS powders and BLA powders increased and reached a plateau. The increase in flour yields of 51.02 g/100 g (BLS powder) and 45.39 g/100 g (BLA powder) were obtained with the addition of 44.44 g/100 g and 37.50 g/100 g β-CD, respectively. The significant increase in flour yield induced by the addition of the carriers could be attributed to the carrier's ability to form outer layers on the droplet and increase the glass transitions temperature (Tg). This could have reduced the flour deposition on drying wall (Ahmed *et al*., 2010). With the increase of β-CD, mushroom flavor of both powders significantly diminished. This had similar results with purple sweet potato flours (Peng *et al*., 2013).

Antioxidant retention rate: When β-CD addition rate increased from 16.67 g/100g to add to 44.44 g/100g, antioxidant retention rates BLS powders and BLA powders first dramatically rose and reached a plateau (Fig. 1B). The increase in antioxidant retention rates of 82.37% and 87.79% were obtained with the addition of 44.44 g/100 g β-CD and from that point decreased slightly.

Taken together, optimal β-CD addition rate of spraying drying BLS and BLA were 44.44 g/100g.

Nutritional and physicochemical properties of BLS powders and BLA powders:

Moisture content and a_w: Nutritional and physicochemical properties of the spray drying powders are presented in Table 2. The moisture content and a_w of the spray drying micro-particles are the important indicators of the drying efficiency and product quality (Rattes and Oliveira, 2007), especially powder stability and storage. a_w of the BLS powders and BLA powders was less than 0.4, which reduced the rates of quality deterioration due to microbial, chemical and enzymatic reactions.

Total sugar, protein and reducing sugar: Both BLS powders and BLA powders had high total sugar value,

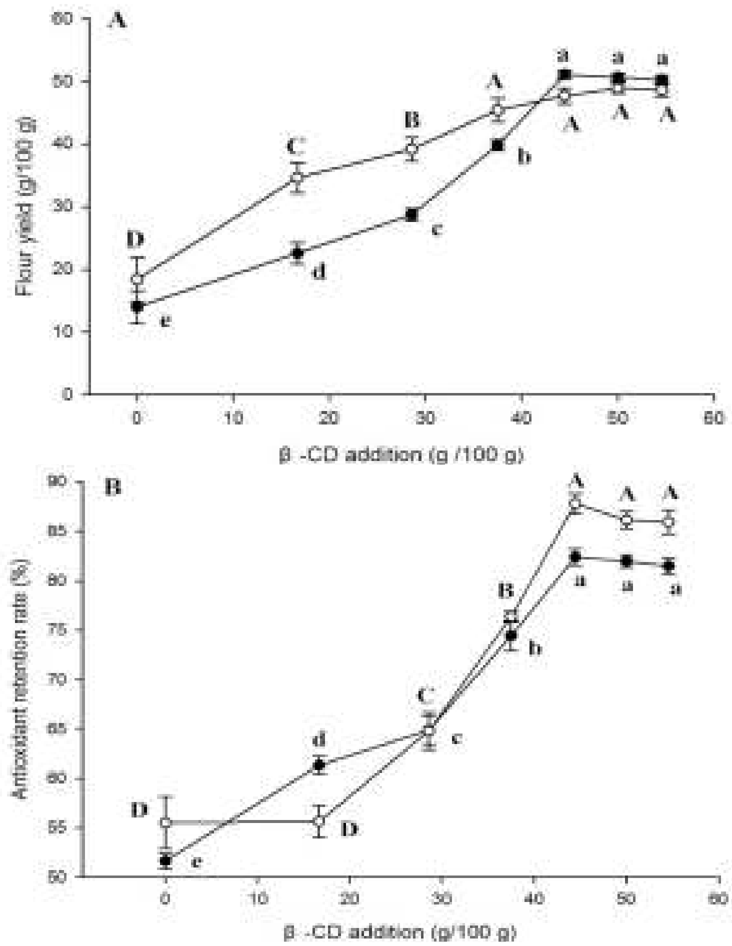


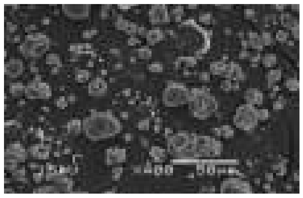
Fig. 1: Effects of the addition of β-CD on the flour yield (A) and antioxidant retention rates (B) of spray drying BLS powders and BLA powders. Values are means of triplicates and error bars represent the SD. Values bearing different lowercase or capital letters indicate significant difference within the same curve by Duncan's test ($p<0.05$); The yield is the ratio of the mass of flour to that of the feed on dry basis; (●): BLS powder; (○): BLA powder

Table 2: Nutritional and physicochemical properties of the spray drying BLS powders and BLA powders (mean ± SD, n = 3)

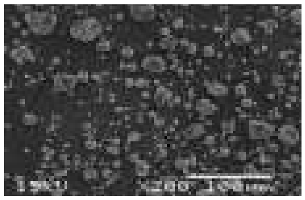
Nutritional properties	BLS powder	BLA powder
Moisture content (g/100 g)	2.88±0.030	3.04±0.04
a_w	0.29±0.010	0.32±0.01
Total sugar (g /100 g)	79.26±0.81	57.19±1.07
Protein (g /100 g)	10.01±0.22	17.500±0.38
Reducing sugar (g/100 g)	0.500±0.06	1.1000±0.09
Ca (mg/100 g)	77.05±0.93	61.770±1.19
Fe (mg/100 g)	23.92±0.68	24.840±0.58
Zn (mg/100 g)	2.570±0.07	1.3000±0.09
Total phenolics (mg gallic acid equivalents/100 g dry matter)	112.0±1.36	125.02±1.42
Bulk density (g/mL)	0.410±0.01	0.4500±0.02
Dispersion time (s)	72.41±5.23	65.640±3.53

which could be due to the added β-CD, an oligosaccharide. Protein content was 10 and 17.5 g/100 g in spray drying BLS and BLA sample, respectively (Table 2). Protein of powders came from dissolution of water-soluble proteins during blanching process of mushroom. Protein and reducing sugar were lost in the spray drying processing because of Maillard reaction. The Maillard reaction is a complex set of reactions initiated by reaction of an amine group of a protein and a carbonyl group of a reducing sugar at high temperatures (Damodaran, 1996). This reaction also led to deeper color of spray drying powder.

Minerals: Mineral elements of nutritional interest are considered bioactive compounds and therefore searching for ideal food products as good dietetic sources or as minerals carriers are of interest. Two kinds of spray drying powders contained calcium, iron, zinc and iron content was abundant.



(a)



(b)

Fig. 2: SEM observation map of the BLS powders (a) and BLA powders (b)

Total phenolics: Total phenolics of BLA powder were higher than BLS powder (Table 2). Polyphenols of two spray drying powder were mainly water soluble due to coming from blanching liquid of mushroom. Polyphenols in plants tend to be water soluble, because they are frequently present as glycosides located in the cell vacuole of plants (Proestos *et al*., 2006). Polyphenols show an antioxidant activity that is even higher than that of antioxidant vitamins, such as vitamin C and E and play an important role in the prevention of chronic diseases such as neurodegenerative and cardiovascular disorders, type 2 diabetes, cancer and osteoporosis (Watson, 2014).

Bulk density and dispersion time: Bulk density is important for packaging and shipping considerations (Phisut, 2012). Bulk density of two spray drying powders was more than 0.4 g/mL (Table 2), showing a nice flowability. Bulk density is mainly influenced by the characteristics of the feed concentrate (e.g., heat treatment, aeration, foaming capacity, viscosity), those of the drying air (inlet and outlet air temperature) and those of the powder (size distribution of particles and residual moisture) (Schuck *et al*., 2012). The difference of bulk density from two kinds of spray drying powders could be due to natural attributes of blanching liquid, because the spray drying conditions are the same. Spray dried powders with higher moisture content tend to have a higher bulking weight, because of the presence of water, which is considerably denser than the dry solid (Chegini and Ghobadian, 2005). This behaviour could also explain BLA powders had the higher bulk density value than BLS powders.

Dispersion time is an important index of water solubility for spray drying powder. Both powders had shorter dispersion time than the red and white dragon fruit powders (Lee *et al*., 2013).

Powder morphology and particle size: Food powder microstructure is the key link between manufacturing conditions and product quality. The understanding of this linkage can have a large impact on product development and improvement (Schuck *et al*., 2012).

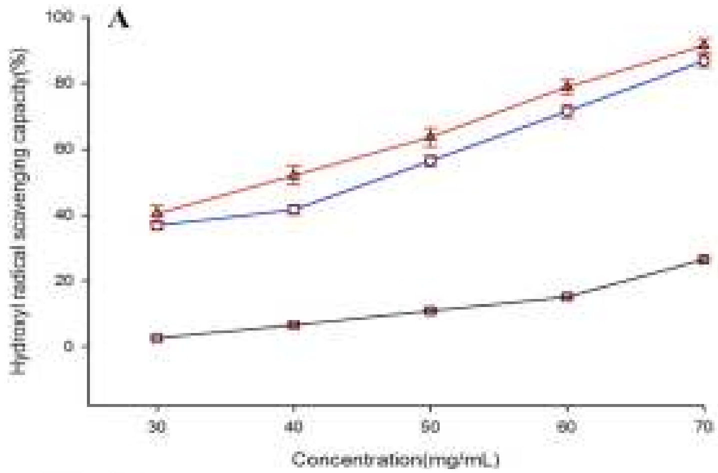
The morphological characteristics of spray drying BLS powders and BLA powders were presented in Fig. 2. Two kinds of powders in this study had spherical particle morphology with smooth surfaces and no surface cracks, corresponding to the characteristics of powders obtained by spray drying (Lee *et al*., 2013; Ferrari *et al*., 2012a). Similar particle morphology had been reported for spray drying red and white dragon fruit (Lee *et al*., 2013), acai (Tonon *et al*., 2008), blackberry (Ferrari *et al*., 2012b) and cactus pear powders (Obón *et al*., 2009). The spherical nature of the particles suggests that the droplets were dried symmetrically. BLS powders and BLA powders particles formed a small portion of agglomerates which appeared to be linked together, with a cavity in its internal structure similar to that found in the Mucilage particles (Cervantes-Martínez *et al*., 2014) and Opuntia stricta particles (Obón *et al*., 2009). The agglomeration of the particles might beattributed to the impacts of electrostatic and Van der Waals forces present in these polyelectrolyte molecules. The formation of poresin the particles could be attributed to desorption of air that the droplets presented during the spray drying (Walton and Mumford, 1999), which influenced the rehydration of the product due to the air contained inside each sphere.

The particle sizes of BLS powders and BLA powders ranged between 5 and 30 μm. Similar range of particle sizes had reported (Ferrari *et al*., 2012a; Vardin and Yasar, 2012). Particle size is also related to the powder bulk density. In general, bulk density decreases when particle size increase.

Antioxidant activities: Figure 3 showed hydroxyl radical scavenging capacity and lipid peroxidation inhibition ability of the spray drying BLS powders and BLA powders. At the same concentration, the antioxidant capacity of the both powders were significantly higher than *β*-CD, especially lipid peroxidation inhibition rate of *β*-CD was substantially zero ranging from the 20 mg/mL to 100 mg/mL. This showed that antioxidant capacity of the spray dried powders were mainly from blanching liquid substances. The antioxidant capacities of powders at same concentration and their EC_{50} values were presented in BLA powder>BLS powder (Table 3). This was the same sequence for the content of total phenolics.

CONCLUSION

Physicochemical and antioxidant properties of the powders are very important to ensure the production of



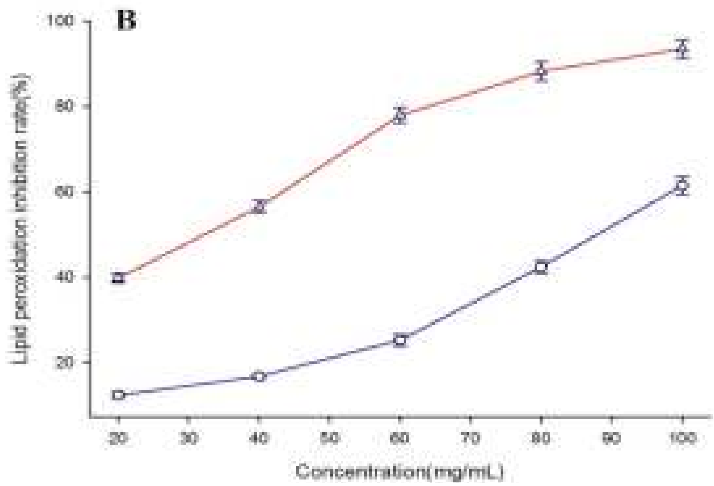


Fig. 3: Hydroxyl radical scavenging capacity (A) and lipid peroxidation inhibition ability (B) of the spray drying BLS powders and BLA powders. Values are means of triplicates and error bars represent the SD. (□), *β*-CD; (○), BLS powder; (Δ), BLA powder

Table 3: Concentration for 50% of maximal effect (EC_{50}) of spray drying BLS powders and BLA powders in measurement of Hydroxyl radical scavenging capacity and lipid peroxidation inhibition activity

	EC_{50} (mg/mL)	
Powder	Hydroxyl radical scavenging capacity	Lipid peroxidation inhibition activity
BLS powder	45.61±0.66	88.52±1.13
BLA powder	38.57±0.48	32.05±0.56

high quality edible fungi powders. BLS powders and BLA powders may have the potential to act as a functional ingredient for enhancing natural antioxidant in food systems. Further study is required on the feasibility of incorporation of the obtained flours into different foods and their impact on the host foods.

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