

Comparison of physicochemical properties of three types of bamboo shoot powders

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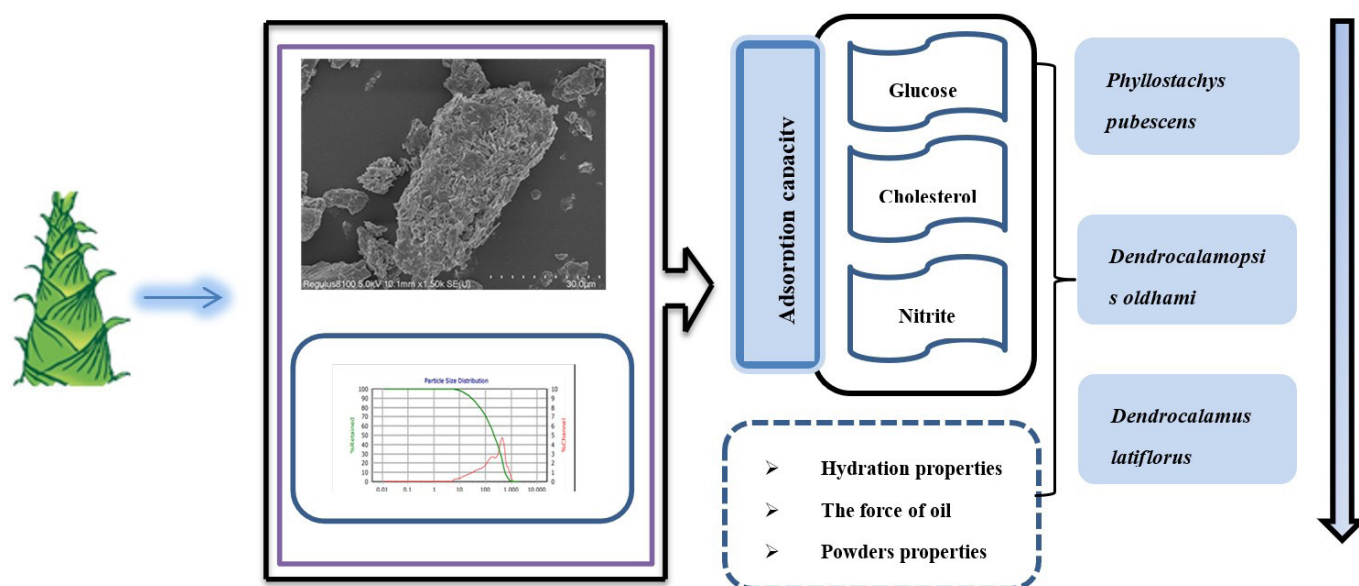
Abstract

Powders were prepared from fresh *Phyllostachys pubescens* bamboo shoots (*P. pubescens*), *Dendrocalamopsis oldhami* bamboo shoots (*D. oldhami*) and *Dendrocalamus latiflorus* bamboo shoots (*D. latiflorus*), and their physical, chemical, adsorption and powder properties were determined. All three of these powders were high in dietary fiber and protein, with *P. pubescens* powder containing the highest concentration of dietary fiber ($50.34 \pm 0.65 \text{ g} \cdot 100 \text{ g}^{-1}$). The water holding, oil holding, and swelling capacities of this powder were all higher than those of the other two kinds of powders. The *P. pubescens* powder also showed the highest capacity to adsorb glucose, cholesterol and nitrite. In addition, the measured repose and slip angles of this powder were lower than those of the other two powders, indicative of it having good fluidity. And the bulk density and tap density of this powder were significantly higher than those of the others as well, indicative of its superior filling property.

Keywords: powder of bamboo shoots; physical and chemical properties; adsorption; powder characteristics.

Practical Application: Providing a scientific data for bamboo powders as a dietary fiber supplement and functional food additive. Bamboo powders had significant effect on weight loss and prevent cancer.

Graphical Abstract



1 Introduction

Bamboo shoots are the young buds of the bamboo subfamily of the family *Gramineae*. There are 116 genera and 1439 species of bamboo in the world, 62% of which are native to Asia; moreover, there are 43 genera and 861 species and subspecies taxa of bamboo in China, of which the area of bamboo forests planted with *Phyllostachys pubescens* (*P. pubescens*) is 1/3 of the total area planted with all other bamboo species (Liu et al., 2018). The shoots of bamboo are tender, tasty and rich in protein, minerals,

vitamins and dietary fiber (Nirmala & Sharma, 2008), which can help prevent cardiovascular diseases, diabetes and other chronic diseases; their shoots in fact represent relatively newly discovered type of dietary fiber resource with great potential for development (Liu et al., 2016). About 40% of the bamboo shoots harvested each year are used for fresh consumption, while the remaining 60% are processed and sold (Tang et al., 2022). However, bamboo shoots are not evenly distributed in terms of

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production areas, market supply is concentrated, fresh products are not easy to store, which makes it difficult to meet the public demand for bamboo shoot products. In contrast, bamboo shoot powder has low water content, is easy to store and transport, and can be used as a high dietary fiber additive in a variety of food products, thus enriching the variety of bamboo shoot products and increasing market supply and diversification, which is important for regulating the market price of bamboo shoot and promoting the development of the bamboo shoot industry.

In the work described in this paper, we analyzed the basic composition, chromaticity, adsorption capacity and powder properties of three bamboo shoot powders, namely those of *P. pubescens*, *Dendrocalamopsis oldhami* bamboo shoot (*D. oldhami*), and *Dendrocalamus latiflorus* bamboo shoot (*D. latiflorus*), to provide experimental data for the processing and utilization of bamboo shoots powder in the food field.

2 Materials and Methods

2.1 Materials and reagents

Bamboo shoots of *P. pubescens* were obtained from a farm in Hengjie Town (Zhejiang, China), those of *D. oldhami* from a farm in a county of Zhangzhou City (Fujian, China), and those of *D. latiflorus* from a farm in Jieyang City (Guangdong, China). A glucose assay kit (deploying the glucose oxidase-peroxidase method) was purchased from Jiancheng Bioengineering Institute (Nanjing, China). *p*-Aminobenzenesulfonic acid and naphthylethylenediamine hydrochloride were purchased from Aladdin Co., Ltd. (Shanghai, China). Analytical grade NaOH, NaCl, concentrated HCl, concentrated H₂SO₄, anhydrous CuSO₄, and K₂SO₄ were purchased from Jiancheng Bioengineering Institute (Nanjing, China).

2.2 Material pretreatment

The fresh bamboo shoots were cleaned and peeled, and the thick old part of the root was removed. Then it was cut into 3-4mm thick slices and soaked in a solution and 0.1% citric acid at 95 °C for 8 minutes, after which they were immediately put into cold water to cool and drain, and then evenly placed in a bamboo sieve and dried in an oven at 60 °C until the moisture content was reduced to about 6%. The dried bamboo shoots were crushed (FW-100, Taisite Instrument Co., Ltd., Tian-jin, China) and passed through a 60-mesh sieve and placed in a desiccator.

2.3 Determination of basic components

Moisture (method 934.06), ash (method 942.05), protein (method 990.03), lipid (method 983.23), total dietary fiber (TDF), soluble dietary fiber (SDF) and insoluble dietary fiber (IDF) (method 978.10) contents were determined using Association of Official Analytical Chemists (AOAC) methods (Association of Official Analytical Chemists, 2006). Soluble total sugar and reducing sugar contents were determined using the method described by Ahmed and Hussain (2013). The contents of free amino acids were determined using the method described by Fouad and Rehab (2015).

Tannin content was determined calorimetrically by following the AOAC method (Association of Official Analytical Chemists, 2005). Oxalic acid (OA) content was determined titrimetrically by being precipitated as calcium oxalate and titrated against standard potassium permanganate (Association of Official Analytical Chemists, 2005). Total phenol and flavonoid contents were determined using the method described by Casas-Forero et al (2020).

2.4 Characterization of chromaticity

A colorimeter (CM5, Konica Minolta, Tokyo, Japan) was used to analyze sample color. The reflected light of the sample was characterized using a black and white plate as a calibration material. ΔE denotes total color difference, calculated using Equation 1.

$$\Delta E = \sqrt{a^{*2} + b^{*2} + L^{*2}} \quad (1)$$

In equation (1), L^* denotes lightness and darkness, a^* and b^* denote color and color purity.

2.5 Determination of Particle size

A particle size analyzer (S3500, Microtrac, Largo, FL) was used to analyze the particle size of bamboo shoot powder, and the dispersion medium used was deionized water.

2.6 Scanning electron microscopy (SEM)

The microstructures of the samples were examined by performing scanning electron microscopy (SEM) using a Hitachi Regulus 8100 scanning electron microscope (Hitachi, Ltd., Tokyo, Japan) operating at 15 kV, according to a previous study. The samples were each placed on a sample stage, and sprayed with gold to form a layer 10 nm thick, in order to observe the sample surface morphology using the microscope. All images were recorded at 1500× magnification.

2.7 Determination of the capacities to hold water, hold oil, swell, and bind water

Determination of water holding capacity

The water holding capacity (WHC) of bamboo shoot powder was determined by using the method described by Yang et al. (2021).

Determination of oil holding capacity

The oil absorption capacity (OAC) of bamboo shoot powder was determined by using the method described by Yang et al. (2021).

Determination of swelling capacity

Water swelling capacity (WSC) of bamboo shoot powder was determined by referring to the method described by Yang et al. (2021).

Determination of water binding capacity (WBC)

Water binding capacity (WBC) of bamboo shoot powder was determined by referring to the method described by Ramos et al. (2020).

2.8 Determination of adsorption properties

Capacity to adsorb glucose (GAC)

The GAC of bamboo shoot powder was determined by referring to the method described by Yang et al. (2019).

Capacity to adsorb cholesterol (CAC)

The CAC was determined according to the method described by Wu et al. (2020), but with slight modifications. Fresh egg yolk was taken, and a volume of 9 mL of distilled water was added to each gram of egg yolk for dilution and stirred well to form an emulsion. For each sample, a mass of 0.5 g of bamboo shoot powder was mixed with 30 mL of the egg yolk emulsion in a centrifuge tube. The pH of the mixtures for one group of samples was adjusted to 2.0 with a solution of 6 mol·L⁻¹ HCl to simulate the human gastric acid environment; and that of the other group was adjusted to 7.0 with a solution of 6 mol·L⁻¹ NaOH to simulate the intestinal environment. Each mixture was shaken in a water bath at 37 °C for 2 h and then cooled to room temperature and centrifuged at 5000 r·min⁻¹ for 15 minutes. The supernatant was collected, and the absorbance was measured at a wavelength of 560 nm. The CAC was calculated using Equation 2.

$$CAC/\mu\text{g}\cdot\text{g}^{-1} = \frac{V_1 \times C_1 - C_2 \times V_2}{W_1} \quad (2)$$

In Equation 2, C_1 is the cholesterol concentration of the original egg yolk solution ($\mu\text{g}\cdot\text{mL}^{-1}$), C_2 is the cholesterol content of the supernatant when adsorption reached equilibrium ($\mu\text{g}\cdot\text{mL}^{-1}$), W_1 is the mass of the sample (g), V_1 is the volume of the original egg yolk solution (mL), and V_2 is the volume of the supernatant.

Capacity to adsorb nitrite (NIAC)

The NIAC was determined by referring to the method described by Yang et al. (2019) with slight modifications. For each sample, a mass of 0.50 g (denoted as W_1) of bamboo shoot powder was thoroughly mixed with 30 mL of a solution of 100 $\mu\text{mol}\cdot\text{L}^{-1}$ NaNO_2 (concentration denoted as C_1 , volume denoted as V_1) in a 50 mL centrifuge tube, and the pH of the mixtures of one group of samples was adjusted to 7.0 with a solution of 6 mol·L⁻¹ NaOH to simulate the intestinal environment, while that of the other group was adjusted to 2.0 with a solution of 6 mol·L⁻¹ HCl to simulate the human gastric acid environment. Each mixture was placed in a 37 °C water bath and shaken for 75 minutes, then centrifuged at 4000 r·min⁻¹ for 15 minutes. The residual concentration of nitrite ions ($\mu\text{g}\cdot\text{mL}^{-1}$) in the supernatant was measured (noted as C_2). NIAC was calculated using Equation 3.

$$NIAC/\mu\text{g}\cdot\text{g}^{-1} = \frac{(C_1 - C_2) \times V_1}{W_1} \quad (3)$$

2.9 Determination of powder properties of the powders

Powder resting angle

Powder resting angle was determined with reference to the method described by Zhao et al. (2009). A glass funnel was fixed vertically on an iron stand, and the height of the lower end of the funnel from the coordinate paper used (H) was set at 3.0 cm. The dried bamboo shoot powder was slowly poured into the funnel, and the powder was allowed to fall naturally until the top of the powder cone on the coordinate paper just touched the lower end of the funnel and stopped. The cone diameter 2R (cm) was read, and the resting angle α was calculated using Equation 4.

$$\alpha = \arctan\left(\frac{H}{R}\right) \quad (4)$$

Powder slip angle

Powder slip angle was determined with reference to the method described by Zhao et al. (2009). A glass plate with a length (L) of 14.0 cm and width of 10.0 cm was placed horizontally on a table and one end of it was fixed. A mass of 3.00 g of bamboo shoot powder was accurately weighed and placed on the non-fixed end of the glass plate, and this end was slowly raised until the surface of the powder started to slide. The height (E) at which the non-fixed end of the glass plate was raised was recorded, and the slip angle β was calculated using Equation 5.

$$\beta = \arcsin\left(\frac{E}{L}\right) \quad (5)$$

Powder packing density

The stacking density (packing density) was calculated by referring to the method described by Cao et al. (2020). A mass (m) of 5.00 g of bamboo shoot powder was slowly added to a graduated cylinder of 10 mL, then the volume (V) of the sample in the cylinder was read, and the packing density Pd was calculated using Equation 6.

$$Pd/\text{g}\cdot\text{mL}^{-1} = \frac{m}{V} \quad (6)$$

Powder vibrational density

Tap density was determined using the method described by Cao et al. (2020). A certain amount of sample was added to a 10 mL measuring cylinder (m_1), and the bottom of the cylinder was then tapped until the volume of material (V_1) no longer decreased, and the resulting combined mass (m_2) was measured. The vibronic density Td was determined using Equation 7.

$$Td/\text{g}\cdot\text{mL}^{-1} = \frac{m_2 - m_1}{V_1} \quad (7)$$

2.10 Statistical analysis

Each experiment was replicated thrice, and all results were expressed using mean $\pm$ standard deviation (SD). Data were processed using Excel 2016; statistical analysis of the data included Duncan's test and ANOVA in SPSS (Version 20.0, SPSS, Inc., Chicago, IL, USA), with $P < 0.05$ considered to indicate significant difference.

3 Results and discussion

3.1 Basic components of the three investigated bamboo shoot powders

As shown in Table 1, all three types of investigated bamboo shoot powders were rich in dietary fiber and protein, with both substances together accounting for more than 65% of the sample mass. The dietary fiber content exceeded 38% of the sample mass in each of the three bamboo shoot powders, with the dietary fiber content of *P.pubescens* powder exceeding 50% of sample mass with a concentration of $50.34 \pm 0.65 \text{ g} \cdot 100 \text{ g}^{-1}$, indicating that dietary fiber was the main component of the bamboo shoot powder. The protein content was higher than 20% in each of the three types of bamboo shoot powder, with the protein content of *D.latiflorus* powder reaching $27.23 \pm 0.10 \text{ g} \cdot 100 \text{ g}^{-1}$. The lipid content of each type of bamboo shoot powder was less than 3%. These results taken together indicated that bamboo shoot powder in general is a high protein and high dietary fiber food source and can be a good food for people on a diet or for weight control (Kumar et al., 2017). Total soluble sugars, free amino acids, tannins and oxalic acid affect the flavor of bamboo shoots: generally the higher the total sugar content, the better the taste of the bamboo shoot (Wang et al., 2020). Of the three types of bamboo powders tested, the highest content of soluble sugars was measured to be in *P.pubescens* powder with a value of $9.69 \pm 0.09 \text{ g} \cdot 100 \text{ g}^{-1}$ and the highest free amino acid content was in *D.oldhami* powder with a value of $37.40 \pm 0.32 \text{ mg} \cdot 100 \text{ g}^{-1}$. And the highest contents of oxalic acid and tannin, components yielding a bitter and astringent taste, were in *D.latiflorus* powder, while the second-highest contents of these components were in the *P.pubescens* powder. These results taken together indicated different species of bamboo shoots to have different flavors. In addition, *P.pubescens* powder had the highest total phenolic content of $5.06 \pm 0.10 \text{ mg} \cdot \text{g}^{-1}$, indicating its good antioxidant activity.

3.2 Colors of the three investigated bamboo shoot powders

The colors of the bamboo shoot powders were analyzed using a color difference meter and the results are shown in Table 1. As shown in Table 1, the b^* values for all three bamboo shoot powders were significantly greater than the a^* values, indicating that the color of each powder was light yellow. The L^* brightness values and ΔE color difference values of the three bamboo shoot powders were similar, with the highest L^* value discerned for the *P.pubescens* powder and the highest ΔE for the *D.latiflorus* powder, indicating that there was no significant difference between their colors. The L^* value (86.56 ± 0.17) and ΔE value (88.16 ± 0.17) of the *D.oldhami* powder were the lowest of the three bamboo shoots, indicating that its color was dull than those of the *P.pubescens* powder and *D.latiflorus* powders. The chemical composition analysis (Table 1) showed that the *D.oldhami* powder contained more free amino acids than did the other powders, and hence the maillard reaction between free amino acids and carbonyl-containing compounds during processing such as drying may have been the main contributor to the slight loss of color of *D.oldhami* powder.

3.3 Particle size distribution of the three investigated bamboo shoot powders

Particle size plays an important role in physicochemical properties and adsorption performance. As shown in Figure 1, all three of them were measured to be micron-sized particles with an average particle size of about 300 μm . The average particle size of the *P.pubescens* powder was measured to be 272.8 μm , less than those of the *D.oldhami* powder (282.4 μm) and *D.latiflorus* powder (306 μm). In addition, its particle size range was 16.88 to 575.7 μm . The particle size distribution curve was similar to that of *D.oldhami* powder. Compared with the particle size distribution of the other two bamboo shoot powders, *D.latiflorus* powder had more concentrated particle size distribution and

Table 1. Comparison of the contents of the basic components and color of the three investigated bamboo shoot powders.

	<i>P.pubescens</i>	<i>D.oldhami</i>	<i>D.latiflorus</i>
Protein/g·100 g ⁻¹	20.61 ± 0.17^c	24.21 ± 0.13^b	27.23 ± 0.10^a
Lipids/g·100 g ⁻¹	1.82 ± 0.15^b	2.64 ± 0.08^a	2.94 ± 0.33^a
Total soluble sugars/g·100 g ⁻¹	9.69 ± 0.09^a	6.65 ± 0.07^c	7.58 ± 0.05^b
Ash/g·100 g ⁻¹	3.38 ± 0.10^c	6.00 ± 0.18^b	6.24 ± 0.04^a
Moisture/g·100 g ⁻¹	5.16 ± 0.32^b	6.31 ± 0.31^a	5.54 ± 0.14^b
Reducing sugar/g·100 g ⁻¹	1.54 ± 0.04^a	1.13 ± 0.02^c	1.35 ± 0.01^b
Free amino acids/mg·100 g ⁻¹	27.49 ± 0.34^b	37.40 ± 0.32^a	23.92 ± 0.11^c
Total dietary fiber/g·100 g ⁻¹	50.34 ± 0.65^a	48.84 ± 0.83^b	38.32 ± 0.56^c
Insoluble dietary fiber/g·100 g ⁻¹	42.61 ± 0.61^a	41.80 ± 1.07^a	33.24 ± 0.23^b
Soluble dietary fiber/g·100 g ⁻¹	7.73 ± 0.16^a	7.04 ± 0.31^b	5.42 ± 0.25^c
Oxalic acid/mg·g ⁻¹	0.14 ± 0.04^b	0.08 ± 0.03^b	0.65 ± 0.09^a
Tannins/mg·g ⁻¹	1.34 ± 0.02^b	0.50 ± 0.01^c	1.61 ± 0.02^a
Total phenols/mg·g ⁻¹	5.06 ± 0.10^a	2.01 ± 0.05^c	3.17 ± 0.05^b
Flavonoids/mg·g ⁻¹	0.56 ± 0.01^c	0.94 ± 0.03^b	1.69 ± 0.01^a
L^*	88.22 ± 0.08^a	86.56 ± 0.17^c	87.24 ± 0.13^b
a^*	0.52 ± 0.02^c	1.68 ± 0.04^a	0.98 ± 0.06^b
b^*	13.94 ± 0.07^c	16.61 ± 0.06^b	24.31 ± 0.30^a
ΔE	89.32 ± 0.09^b	88.16 ± 0.17^c	90.57 ± 0.19^a

Note: Different letters marked in the same row indicate significant differences between treatments ($P < 0.05$).

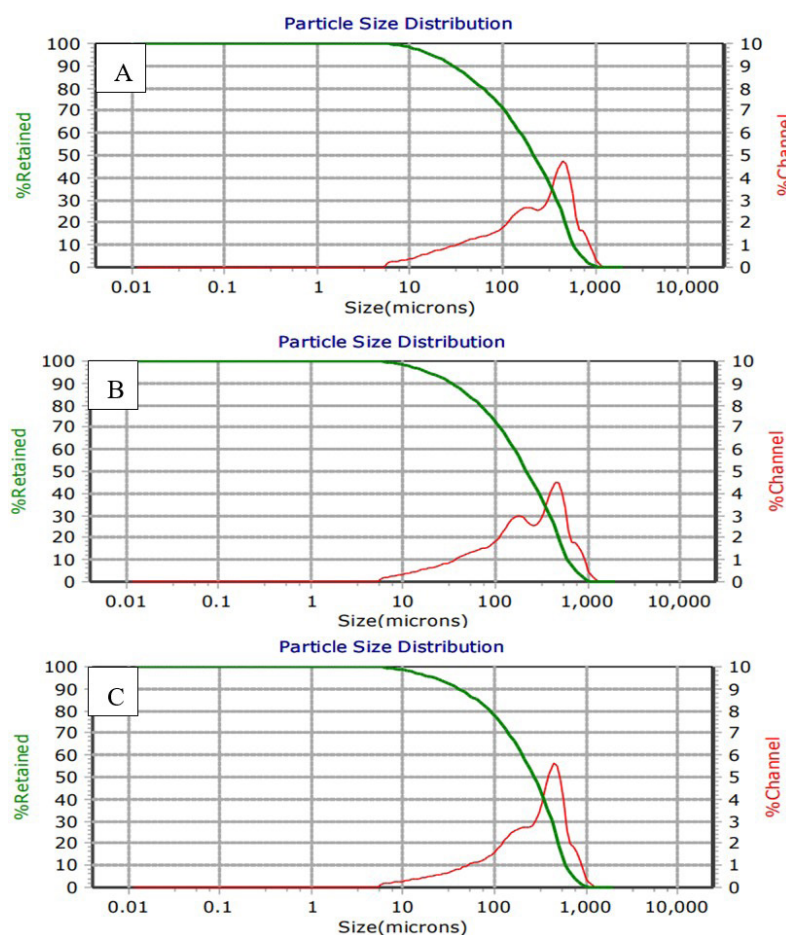


Figure 1. Particle size distributions of the three investigated bamboo shoot powders (A: *P.pubescens* powder B: *D.oldhami* powder C: *D.latiflorus* powder).

more large particles, This difference may be related to the shear force received when the powder is crushed, or to the shoots of different species of bamboo having different dietary fiber contents, with the highest soluble dietary fiber content in the *P.pubescens* powder, which showed the smallest average particle size and more uniform particles.

3.4 Microstructures of the three investigated bamboo shoot powders

The acquired SEM images of the three bamboo shoot powders are shown in Figure 2. The surface of *P.pubescens* powder was observed to be rugged, with many small flakes gathered together, a large specific surface area, and an irregular network structure—features resulting in abundant pores and exposed polar groups, and hence likely to favor adsorption of and capacities to hold various substances such as water, oil, and cholesterol (Zheng et al., 2018). *D.oldhami* powder also showed abundant pores as well as cracks on its surface, features that may be related to the reduced protein content near the bamboo shoot fibers. Compared to these powders, *D.latiflorus* powder showed a flatter surface with a dense network structure and fewer folds and pores. We would expect these microstructures of the three bamboo shoot powders to have some influence on their physicochemical properties.

3.5 WHC, WSC, WBC and OHC of the three investigated bamboo shoot powders

We also measured the WHC, WSC, and OHC of the three bamboo shoot powders. Of the three investigated powders, *P.pubescens* powder showed the highest values of each of these capacities (Table 2), while *D.latiflorus* powder showed the lowest values. Note that the total dietary fiber and soluble dietary fiber contents of the three types of bamboo shoot powders were found, as described above in our compositional analysis, to follow the order *P.pubescens* powder > *D.oldhami* powder > *D.latiflorus* powder. And note that dietary fiber in general contains a large number of hydrophilic groups such as carboxyl groups and hydroxyl groups that easily form hydrogen bonds with water molecules and facilitate water adsorption and permeation, with more water absorption resulting in greater swelling of any powder containing such fiber. *P.pubescens* powder has been shown to contain abundant dietary fiber, and soluble dietary fiber can increase the viscosity and adsorption capacity of the powder (Wang et al., 2017), hence resulting in relatively high WHC and WSC of this powder. A previous study showed a positive correlation between the OHC of dietary fiber and the content of soluble dietary fiber (Lv et al., 2017), explaining the finding in the current work of *P.pubescens* powder displaying both the highest content of soluble dietary fiber ($7.73 \pm 0.16 \text{ g} \cdot 100 \text{ g}^{-1}$)

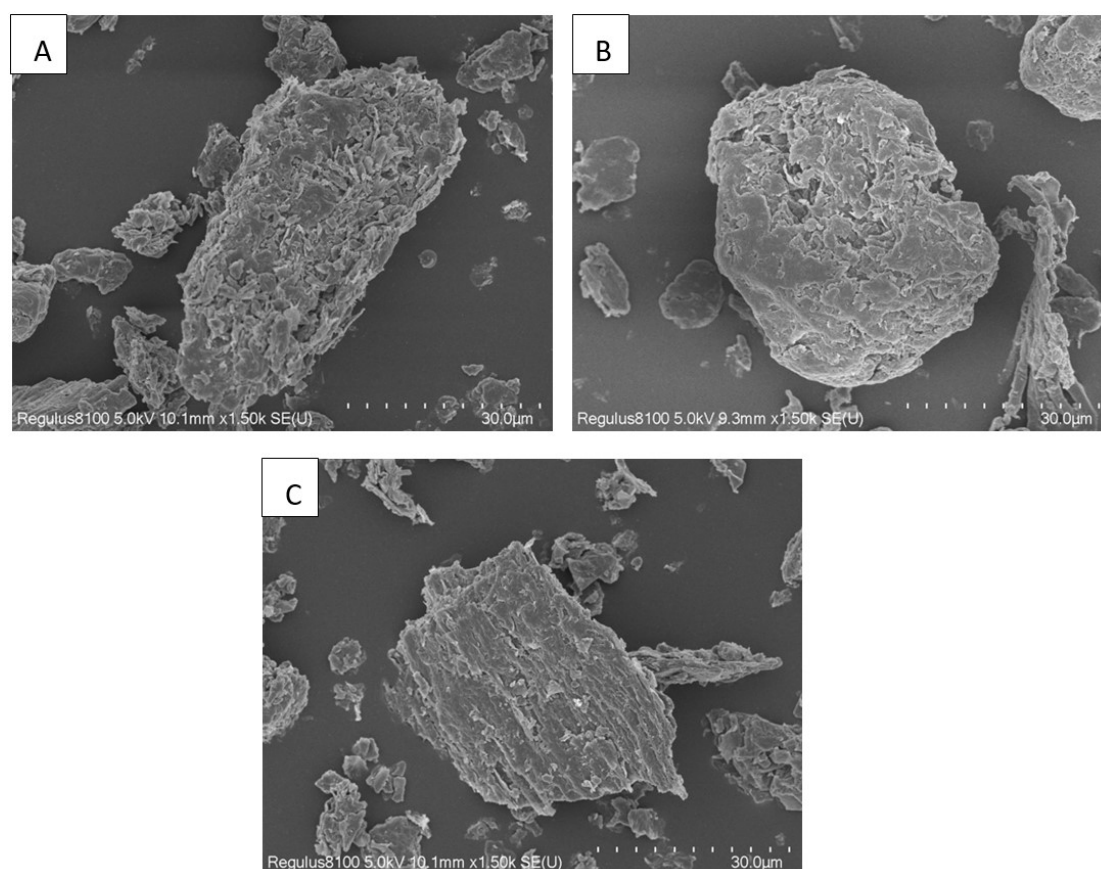


Figure 2. Scanning electron micrographs of the three investigated bamboo shoot powders $\times 1500$ (A: *Ppubescens* powder B: *D.oldhami* powder C: *D.latiflorus* powder).

Table 2. Physical and chemical properties of the three investigated bamboo shoot powders.

Bamboo species	Water holding capacity/ $\text{g}\cdot\text{g}^{-1}$	Swelling capacity / $\text{g}\cdot\text{g}^{-1}$	Binding capacity / $\text{g}\cdot\text{g}^{-1}$	Oil holding capacity / $\text{g}\cdot\text{g}^{-1}$
<i>Ppubescens</i>	8.17 ± 0.11^a	13.43 ± 0.32^a	11.97 ± 0.34^a	2.31 ± 0.12^a
<i>D.oldhami</i>	7.82 ± 0.49^a	12.71 ± 0.35^b	10.41 ± 0.10^b	2.13 ± 0.11^a
<i>D.latiflorus</i>	6.92 ± 0.33^b	10.72 ± 0.34^c	9.43 ± 0.47^c	2.09 ± 0.25^a

Note: Different letters marked in the same column indicate significant differences between treatments ($P < 0.05$).

and the best OHC of the three types of bamboo shoot powders investigated. In addition, the average particle size of *Ppubescens* powder being the lowest of the three bamboo shoot powders, and hence having the largest specific surface areas and largest contact areas with substances such as water or oil, also contributed to its superior WHC, OHC, WSC and WBC. The WHC and OHC of the three bamboo powders were significantly higher than the WHC ($4.17 \pm 0.04 \text{ g}\cdot\text{g}^{-1}$) and OHC ($0.89 \pm 0.03 \text{ g}\cdot\text{g}^{-1}$) of sea buckthorn pomace powder made by Hussain et al. (2021).

3.6 Adsorption capacities of the three investigated bamboo shoot powders

GAC

GAC is an important predictor of glucose absorption capacity of dietary fiber (Yang et al., 2019). As shown in Figure 3, three bamboo shoots powders had significant adsorption effect on glucose, and the absorption capacity was positively correlated

with glucose concentration. For glucose concentrations of $100 \text{ mmol}\cdot\text{L}^{-1}$ and $200 \text{ mmol}\cdot\text{L}^{-1}$, the capacities of *Ppubescens* powder to adsorb glucose were, respectively, $4.01 \pm 0.04 \text{ mmol}\cdot\text{g}^{-1}$ and $13.50 \pm 0.01 \text{ mmol}\cdot\text{g}^{-1}$, i.e., 2.84 and 9.57 times the glucose concentration of $50 \text{ mmol}\cdot\text{L}^{-1}$. The GAC of the three bamboo shoot powders were found to follow the order *Ppubescens* powder $>$ *D.oldhami* powder $>$ *D.latiflorus* powder, but the difference between the three was not significant. This result may have been related to the different dietary fiber contents and soluble dietary fiber contents of the three bamboo shoot powders. For a glucose concentration of $100 \text{ mmol}\cdot\text{L}^{-1}$, the GAC of *Ppubescens* powder was slightly lower than that of *Ppubescens* root dietary fiber powder ($4.63 \text{ mmol}\cdot\text{g}^{-1}$) (Yang et al., 2021), indicating that the GAC of bamboo shoot powder was not much different from that of just the bamboo shoot root dietary fiber. Therefore, bamboo shoot powder as an additive added to other foods, can effectively reduce the levels of glucose in the body.

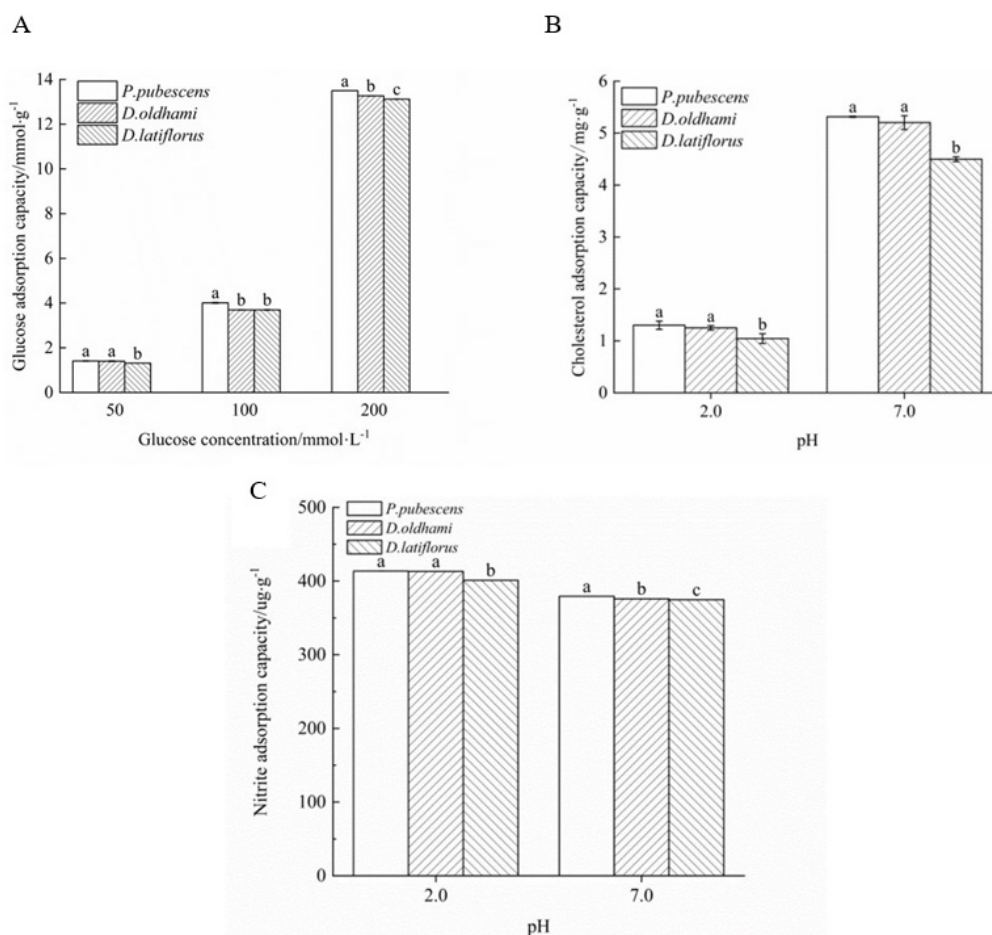


Figure 3. Comparison of glucose, cholesterol and nitrite adsorption capacities of the three investigated bamboo shoot powders. Note: Different letters marked in the same figure indicate significant differences between treatments ($P < 0.05$). ($p < 0.05$).

CAC

Excess cholesterol and reduced cholesterol absorption in the body are major factors in the development of certain diseases such as cardiovascular disease, type 2 diabetes and obesity. One of the most important effects of dietary fiber has been shown to be its apparent reduction of plasma cholesterol levels and the incidence of atherosclerosis (Zheng et al., 2018). As shown in Figure 3, the CAC of the three bamboo shoot powders at pH 2.0 (simulated human gastric environment) and pH 7.0 (simulated human small intestine environment) were found to follow the order *P. pubescens* powder > *D. oldhami* powder > *D. latiflorus* powder, i.e., *P. pubescens* powder showed the strongest CAC. Also, for each of the three bamboo shoot powders, the CAC at pH 7.0 was significantly higher than at pH 2.0. Specifically, the CAC of *P. pubescens* powder, *D. oldhami* powder and *D. latiflorus* powder were $5.32 \pm 0.01 \text{ mg} \cdot \text{g}^{-1}$, $5.20 \pm 0.13 \text{ mg} \cdot \text{g}^{-1}$ and $4.50 \pm 0.05 \text{ mg} \cdot \text{g}^{-1}$, respectively, i.e., 4.09, 4.16 and 4.33 times higher than the adsorption capacities at pH 2.0 ($1.30 \pm 0.08 \text{ mg} \cdot \text{g}^{-1}$, $1.25 \pm 0.04 \text{ mg} \cdot \text{g}^{-1}$ and $1.04 \pm 0.09 \text{ mg} \cdot \text{g}^{-1}$), indicating that bamboo shoot powder would adsorb more cholesterol in the small intestine than in the stomach. These findings, combined with the above-described compositional analysis findings of *P. pubescens* powder having the highest dietary fiber content ($50.34 \pm 0.65 \text{ g} \cdot 100 \text{ g}^{-1}$) and soluble dietary fiber content ($7.73 \pm 0.16 \text{ g} \cdot 100 \text{ g}^{-1}$) of the three powders

investigated, indicated a correlation of the CAC of bamboo shoot powder with its dietary fiber content (Jiang et al., 2022). The relatively high capacity of *P. pubescens* powder to adsorb cholesterol may also be attributed to this powder having the smallest average particle size and hence largest specific surface area and thus highest number of exposed active groups of the three bamboo shoot powders investigated.

NIAC

Nitrite is a kind of N-nitroso compound that is harmful to the human body and induces the development of cancer by reacting with secondary amines and amides under acidic conditions. Dietary fiber can adsorb NO_2^- , so it has a cancer prevention effect (Song et al., 2018). As shown in Figure 3, all three bamboo shoot powders adsorbed nitrite ions at pH 2.0 (simulated human gastric environment) and pH 7.0 (simulated human small intestine environment), but with the NIAC at pH 2.0 significantly higher than that at pH 7.0. Note also that, at a given pH, there was no significant difference between the capacities of the three bamboo shoot powders to adsorb NO_2^- , although *D. latiflorus* powder showed a slightly lower such capacity than did the other two powders. The relatively low NIAC of the bamboo shoot powders at pH 7.0, compared to

those at pH 2.0, can be attributed to the carboxyl groups on the surface of the dietary fiber having ionized to carboxylates at pH 7.0 and hence increasing the density of negative charges, with the repulsive capacity between the like negative charges having been increased, releasing the originally absorbed NO_2^- and hence yielding the decreased NIAC. In contrast, at the highly acidic pH 2.0 conditions, the glyoxalic acid contained in the structure of the dietary fiber, especially reactive groups such as phenolic acid, would have had a strong adsorption to nitroso (Lyu et al., 2021). In addition, the relatively high content of the colloidal and high-specific-surface-area soluble dietary fibers in *Ppubescens* powder and *D.oldhami* powder likely provided a strong advantage for the physical adsorption of NO_2^- (Zheng et al., 2021). The slightly lower capacity of the *D.latiflorus* powder than of the other powders to adsorb NO_2^- may have been due to its relatively low soluble dietary fiber content and large particle size having exposed fewer reactive groups. The overall high NIAC of bamboo shoot powders has been suggested to provide a potential for its development as a functional food for gastric cancer prevention (Chu et al., 2019).

The strong abilities of dietary fiber to adsorb glucose, cholesterol and nitrite constitute an important material basis for the good adsorption abilities exhibited by bamboo shoot powder. The adsorption performance of bamboo shoot powder is not only affected by the dietary fiber content in the sample, but also the particle size of the powder and the adsorption environment. The superior adsorption capacities displayed by *Ppubescens* powder can be attributed to its high contents of total dietary fiber and soluble dietary fiber and to its relatively small powder particle size and hence large specific surface area. When bamboo shoot powder is consumed together with other foods, its good adsorption ability can reduce the GAC, CAC and NIAC from the food into the body, which can in turn reduce the risk of hyperglycemia and hyperlipidemia occurring in the consumer of the food.

3.7 Powder properties of the three investigated bamboo shoot powders

The higher bulk density and vibrational density of a powder, the better its fillability (Murakami et al., 2001). As summarized in Table 3, of the three types of bamboo root powders investigated, *Ppubescens* powder showed the highest bulk density, with a value of $0.55 \pm 0.02 \text{ g} \cdot \text{mL}^{-1}$, while *D.latiflorus* powder showed the lowest bulk density, with a value of $0.46 \pm 0.01 \text{ g} \cdot \text{mL}^{-1}$. After being subjected to shaking, the resulting compaction density of *Ppubescens* powder was still the highest, reaching $0.88 \pm 0.05 \text{ g} \cdot \text{mL}^{-1}$, obviously higher than the compaction density

of *D.latiflorus* powder, indicating that the filling performance of *Ppubescens* powder was superior. The analysis concluded that the average particle size of *Ppubescens* powder was the lowest among the three powders, the powder particles were smaller and the particle size distribution was more concentrated, and the stacking produced low porosity and therefore higher density.

The resting angle of a material indicates the ability of the material particles to agglomerate, while the sliding angle indicates the ability of the material particles to adhere to a contact surface (Maa et al., 2004); the magnitude of the value of the sliding angle is related to the good or bad powder flowability (Wei et al., 2019). As shown in Table 3, the resting angles of the three bamboo shoot powders were significantly different from one another, as were their sliding angles ($P < 0.05$). The resting and sliding angles of the *Ppubescens* powder, at $48.06 \pm 0.08^\circ$ and $48.13 \pm 1.00^\circ$, respectively, were the smallest of the three powders, indicating its superior fluidity. The resting and slip angles of *D.oldhami* powder were the largest of the three powders, indicating that its fluidity was the worst, which may be related to the high moisture content of this powder. The high moisture content of the material apparently made it easy for the particles to gather together, yielding increased friction and adhesion between the particles, and hence worsened the fluidity (Dhanalakshmi et al., 2011).

4 Conclusions

In summary, in the work described in this paper, the basic composition and physicochemical properties of shoot powders from three types of bamboo and their powder properties were investigated. The results showed that the main chemical components of the three bamboo shoot powders were dietary fiber and protein. The measured dietary fiber contents were $50.34 \pm 0.65 \text{ g} \cdot 100\text{g}^{-1}$ for *Ppubescens* powder, $48.84 \pm 0.83 \text{ g} \cdot 100\text{g}^{-1}$ for *D.oldhami* powder and $38.32 \pm 0.56 \text{ g} \cdot 100 \text{ g}^{-1}$ for *D.latiflorus* powder, while the protein content was more than 20% for each of them, indicating that bamboo shoot powders are a food source with high levels of protein and dietary fiber. Compared with *D.latiflorus* powder and *D.oldhami* powder, *Ppubescens* powder showed better WHC, WSC, and OHC, and also showed high capacities for adsorbing glucose, cholesterol and nitrite, reflecting the good performance of products having high levels of dietary fiber. Meanwhile, the average particle size ($272.8 \mu\text{m}$) of *Ppubescens* powder was lower, and the flowability and fillability of the powder were better than those of the other two bamboo shoot powders. All told, *Ppubescens* powder was found as a high protein and high dietary fiber food material with excellent adsorption and swelling properties, to develop it into functional products to balance the body blood sugar blood fat is very valuable.

Table 3. Comparison of the comprehensive powder properties of three investigated bamboo shoot powders.

	<i>Ppubescens</i>	<i>D.oldhami</i>	<i>D.latiflorus</i>
Bulk density/ $\text{g} \cdot \text{mL}^{-1}$	0.55 ± 0.02^a	0.49 ± 0.00^b	0.46 ± 0.01^c
Vibrational density/ $\text{g} \cdot \text{mL}^{-1}$	0.88 ± 0.05^a	0.82 ± 0.02^a	0.79 ± 0.06^a
Angle of repose/ $^\circ$	48.06 ± 0.08^c	52.59 ± 0.16^a	51.51 ± 0.31^b
Slip angle/ $^\circ$	48.13 ± 1.00^c	68.5 ± 0.50^a	66.39 ± 0.39^b

Note: Different letters marked in the same row indicate significant differences between treatments ($P < 0.05$).

List of Abbreviations

Phyllostachys pubescens bamboo shoot *P.pubescens*

Dendrocalamopsis oldhami bamboo shoot *D.oldhami*

Dendrocalamus latiflorus bamboo shoot *D.latiflorus*

TDF: total dietary fiber

SDF: soluble dietary fiber

IDF: insoluble dietary fiber

WRC: water retention capacity

OAC: oil absorption capacity

WSC: water swelling capacity

WBC: water binding capacity

GAC: capacity to adsorb glucose

CAC: capacity to adsorb cholesterol

NIAC: capacity to adsorb nitrite

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