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A comparative evaluation of chemical composition and nutritional value of bamboo rice and major cereals reveals the potential utility of bamboo rice as functional food

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ABSTRACT

Bamboo rice refers to the edible seeds collected from bamboo plants, but the nutritional and chemical compositions of bamboo rice are unknown. Here, we evaluated the nutritional value of two types of bamboo seeds by comparing them to rice and wheat. The fiber, protein, and microelement contents were much higher in bamboo seeds than in rice and wheat seeds. The flavonoids content was 5- and 10-folds higher in Moso bamboo seeds than in rice and wheat seeds, respectively. Amino acid profiles exhibited that most of amino acids were abundant in bamboo seeds compared to rice and wheat seeds. While water-soluble B vitamins and fatty acids in bamboo seeds were similar to those in rice and wheat seeds. Accordingly, rice and wheat may thus be substituted by bamboo rice which is a potentially functional food. Its high flavonoid content may be further exploited by the food industry.

1. Introduction

Bamboo is a tree-like grass species that belongs to the family Gramineae, which also includes other cereal grasses (e.g., rice, wheat, and barley) (Mustafa et al., 2021; Yeasmin et al., 2015). There are currently more than 120 genera and 1,600 species of bamboo plants (Canavan et al., 2017), which are widely distributed in tropical and subtropical regions of mostly found in Asian countries (Bystriakova et al., 2003). Bamboo is an important forest resource used as a wood substitute and as raw material for medicine and food (Nirmala et al., 2018). Bamboo leaves and bark shavings have clinical usage, and the juvenile shoots are consumed as a vegetable (Nirmala et al., 2018). An often overlooked raw material is bamboo rice.

Bamboo rice is the common name for seeds of wild bamboo plants (Soumya et al., 2014). Some bamboo seeds look similar to rice grains. *Bambusa arundinacea*, a native bamboo species in India, produces brown seeds which resemble rice grains after dehusking (Haldipur & Srividya 2021). However, bamboo seed shapes have diversity (e.g., ellipse, oblong, and ovoid or broad ovoid) (Yang et al., 2021). Bamboo rice consumption has long history and still preferred in regions like southern India and southwestern China (Haldipur & Srividya 2021; Yang et al., 2021). The bamboo rice harvesting varies among regions. Fallen seeds are collected via clean tablecloth placed under the bamboo canopy before seeds set (Soumya et al., 2014). The collected bamboo seeds are stored and consumed as food. People generally cook bamboo seeds as rice. The collected bamboo seeds are washed in running water two or three times, soaked, drained, followed by boiling or cooking with other cereals (Prasad et al., 2021). On the other hand, bamboo seeds are also traded as medicine and used as other commodities like milled bamboo seeds, bamboo seeds oil, cookies made from bamboo seeds, etc. (Kiruba et al., 2007; Prasad et al., 2021; Soumya et al., 2014). People consume bamboo seeds who believe that bamboo seeds are rich in nutrients and contain components with beneficial effects on human health (Kiruba et al., 2007). In some tribal regions, people use bamboo seeds as an aphrodisiac and for treating digestive ailments and urinary tract infections (Soumya et al., 2014). However, the exact chemical composition and nutritional value of bamboo seeds are unclear and there is a lack of scientific evidence regarding their medicinal functions. Question arises if bamboo seeds can be used as a functional food?

Bamboo species are classified as monopodial and sympodial

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according to their rhizome structures (Zhao et al., 2014). Based on these types, seeds were obtained from two typical bamboo species, *Phyllostachys edulis* and *Dendrocalamus asper*, in this study. Specifically, *P. edulis* (also called Moso bamboo) is a monopodial bamboo species (Peng et al., 2013) while *D. asper* (also called sweet bamboo) is a sympodial bamboo species. Both bamboo species are economically valuable, widely distributed, and well-studied (Mustafa et al., 2021; Peng et al., 2013). Seeds from both bamboo species have multiple uses. They can be used as explant materials for tissue culture systems. Moreover, they may be employed to produce seedlings for propagation or consumed as food (Mustafa et al., 2021). Regarding their use as food, basic information, such as their chemical composition and nutritional value remain relatively uncharacterized.

In the present study, the chemical compositions and nutritional characteristics of *P. edulis* and *D. asper* bamboo rice were investigated. The data obtained were compared with corresponding data of wheat and rice (three rice cultivars and three wheat cultivars that are widely cultivated in China). It was revealed that bamboo rice of both species were nutrients rich. Bamboo rice may thus be a viable alternate of rice and wheat. It should however be further exploited as functional food or ingredient.

2. Materials and methods

2.1. Materials

P. edulis and *D. asper* seeds were collected from Guangxi province, China. The rice (Jiayou5, Fengliangyou4, and Liangyoupeijiu) and wheat (Jimai325, Kenong199, and Shi4185) seeds were provided by China National Rice Research Institute and Institute of Genetics and Developmental Biology, respectively. Seeds were dried in an oven and then ground to a powder using an electric pulverizer. The powder was sieved through 20-mesh sieve and then processed and analyzed as described below.

2.2. Morphological trait analysis

To analyze *P. edulis* and *D. asper* seed morphology, the length and width of 90 randomly selected seeds were measured using a vernier caliper for both bamboo species. The analysis was performed using three independent replications. To determine the 1,000 seed weight, three replicates of 1,000 randomly selected seeds were dried to a constant weight at 40°C in an oven and then weighed. Some of the randomly selected seeds were dehusked and photographed.

2.3. Proximate composition analysis

The proximate composition of the seed samples was determined as per the standard Association of Official Analytical Chemists procedures (AOAC, 2005). The moisture content was measured based on weight loss after drying to a constant weight in an oven at 105°C. The ash weight was determined after the samples were carbonized for 0.5 h at 300°C in a muffle furnace and then incinerated for 4 h at 570°C. The fat content was determined via an exhaustive extraction method involving diethyl ether and petroleum ether as well as a Soxhlet apparatus. Kjeldahl method was employed to measure protein amount (N × 6.25) (Method No.978.04) (AOAC, 2005). Crude fiber quantity was ascertained after digesting a known weight of fat-free sample in refluxing 1.25% sulfuric acid and 1.25% sodium hydroxide (Method No.930.10) (AOAC, 2005). The carbohydrate content was calculated using the following formula: 100 − (% crude fiber + % fat + % protein + % ash + % moisture).

2.4. Sugar and soluble protein analysis

Reducing sugars were extracted and determined via 3,5-dinitrosalicylic acid (DNS) colorimetic method described by Deshavath et al. (2020). To quantify the starch content, 1 g sample was extracted twice with 80% ethanol and then twice with 52% perchloric acid. The absorbance (640 nm) of the extract was determined using a spectrophotometer (UV 2600; Shimadzu Corporation, Tokyo, Japan) according to the anthrone-sulfate method described by Fernandes et al. (2012). Using the standard curve for glucose, the starch content was expressed as g glucose equivalent/100 g sample.

To determine the total sugar content, 1 g sample was mixed with 10 ml 6 M HCl and 15 ml Milli-Q water. The mixture was incubated for 30 min at 100°C in a water bath. After a complete hydrolysis step, a phenolphthalein indicator was added and the mixture was cooled to room temperature before 1 M NaOH was added until the mixture had a neutral pH. The solution was filtered before the total sugar content was determined according to the 3,5-DNS colorimetry-based method described by Wood et al. (2012). The absorbance recorded at 540 nm using a spectrophotometer. Using the standard curve for glucose, the total sugar content was expressed as g glucose equivalent/100 g sample.

To measure the soluble protein content, 1 g sample and 5 ml 50 mM PBS (pH 7.8) were thoroughly mixed and then centrifuged at 10,000 g for 15 min. The supernatant absorbance was recorded at 595 nm for quantifying soluble protein content as described by Bradford (1976). The soluble protein content was expressed as mg bovine serum protein equivalent/100 g sample, by using standard curve for bovine serum protein.

2.5. Phytochemical analysis

Phytic acid content was determined according to the slightly modified method by Lemmens et al. (2018). Briefly, 0.5 g sample prepared as described above was extracted with 5.5 ml 0.01 M HCl for 24 min at 40°C using an ultrasonicator. The mixture was centrifuged at 4,000 g for 15 min. The Wade reagent [0.03% iron (III) chloride and 0.3% sulfosalicylic acid] was used to estimate the phytate content in the clear supernatant. The absorbance (500 nm) of the supernatant was measured using a spectrophotometer. The phytate concentration was calculated on the basis of the standard curve produced using sodium phytate and expressed as mg sodium phytate equivalent/g sample.

The total flavonoid content was determined as described by Woisky and Salatino (1998). Flavonoids were extracted from 0.5 g sample using 20 ml 80% ethanol. After centrifuging the solution at 3,300 g for 15 min, a 200 μl aliquot of the supernatant was mixed with 300 μl 5% $NaNO_2$ before 300 μl $Al(NO_3)_3$ was added and the mixture was left undisturbed for 5 min. Next, 2 ml 1 M NaOH was added and the total volume of the mixture was adjusted to 10 ml using Milli-Q water. The solution was vigorously mixed and left undisturbed for 10 min. The absorbance (510 nm) was measured using a spectrophotometer. The total flavonoid content was quantified using a standard curve for rutin and expressed as mg rutin equivalent/g sample.

The phenolic content was determined according to the Folin-Ciocalteu colorimetry-based method described by Kupina et al. (2018). More specifically, polyphenols were extracted from 0.5 g sample using 12 ml 60% acetone. The solution was centrifuged at 3,300 g for 15 min and then a 1 ml aliquot of the supernatant in 5 ml Milli-Q water was mixed with 0.5 ml Folin-Ciocalteu reagent. After 10 min, 1.5 ml 20% sodium carbonate was added to the mixture and adjusted up to total volume of 10 ml with Milli-Q water, which was incubated for 20 min at 40°C in a water bath. The absorbance (760 nm) was measured using a spectrophotometer. The phenolic content was quantified using a standard curve for gallic acid (0–25 μg/ml) and expressed as mg gallic acid equivalent/g sample.

2.6. Elemental determination

Bamboo, rice, and wheat seeds were oven dried for 3 days at 70°C. The seeds were digested with HNO_3 at temperatures as high as 140°C. The digested solution was diluted to 20 ml with Milli-Q water and

elemental concentrations were determined using the ICP–MS system (X series 2; Thermo Scientific, MA, USA). A certified standard ICP-MS calibration solution 2 (ICP-MS-CAL2-1) was used for quality control. The recovery rates of elements in the certified reference material ranged from 98% to 100% during the determination.

2.7. Total amino acid analysis

Amino acids were extracted by hydrolyzing 100 mg powdered seed material with 10 ml 6 M HCl in a sealed hydrolysis tube that was heated at 110°C for 24 h in an oven. The solution was filtered, after which a 1 ml aliquot was dried in a glass tube using the termovap sample concentrator. The dried material was re-dissolved in 1 ml 0.02 M HCl and filtered through a 0.22 μm membrane. The filtered sample was used for the amino acid analysis. Specifically, the amino acid composition was analyzed using the L-8900 High-Performance Amino Acid Analyzer (Hitachi, Tokyo, Japan).

2.8. Water-soluble vitamin analysis

The water-soluble vitamins were extracted using water as described by Zafra-Gómez et al. (2006). Briefly, 0.5 g sample was mixed with 4.5 ml Milli-Q water and ultrasonicated for 10 min. The solution was filtered through a 0.22 μm membrane and then a 1 ml aliquot was collected for the analysis of the water-soluble vitamins thiamin, niacin, pyridoxine, pantothenic acid, folate, and riboflavin using an ultra-high performance liquid chromatography system (1260 Infinity II Prime; Agilent, Palo Alto, USA) that included the EC-C18 column (2.1 × 100 mm, 2.7 μm, Poroshell 120; Agilent). The program setting was based on that used by Zafra-Gomez et al. (2006). Acetonitrile and 25 mM KH_2PO_4 were used for the gradient elution at a flow rate of 1.0 ml/min, with detection wavelengths of 205, 246, 261, 267, 283, and 290 nm. The vitamins corresponding to the peaks were identified according to the peak retention times and a comparison with the peaks for the standards. The vitamin contents were calculated according to the peak area for the corresponding standard.

2.9. Fatty acid analysis

Fatty acid profile was characterized after a transesterification procedure using a slightly modified version of the method described by Barros et al. (2013). Each sample (0.5 mg) was methylated using 1 ml methanol/sulfuric acid/toluene [2:1:1 (v/v/v)]. The solution was kept in a water bath at 70°C for 60 min. Next, 1 ml *N*-hexane was added and the solution was thoroughly mixed before it was left undisturbed for 5 min. The supernatant was collected and analyzed using a gas chromatography system (Trace1300E; Thermo Fisher, Waltham, MA, USA) that included a quartz capillary column (30 m × 0.25 mm × 0.25 μm). The temperature was maintained at 140°C for 1 min, increased to 250°C at 4°C/min, and held for 5 min. Each sample was analyzed for 33.5 min. Nitrogen, hydrogen, and air were applied as the carrier gases at flow rates of 25, 30, and 400 ml/min, respectively. The injector and detector temperatures were 220 and 275°C, respectively. The fatty acids corresponding to the peaks were identified according to the retention times and a comparison with the authenticated standards analyzed under the same conditions.

2.10. Statistical analysis

Unless otherwise stated, the experiments were completed using three replicates. The generated data were expressed as the mean ± standard deviation. Data were analyzed using Excel (Microsoft, USA). The SPSS software (verison 22) was used for the ANOVA, with $P < 0.05$ set as the threshold for significance.

3. Results and discussion

3.1. Overview of bamboo seed morphology

P. edulis seeds were thin and long (Fig. S1A), whereas *D. asper* seeds were thick and short (Fig. S1B). The seed lengths and widths were 13.0 and 2.0 mm for *P. edulis* and 4.9 and 2.7 mm for *D. asper*, respectively (Fig. S1C, D). The 1,000 seed weight was significantly higher for *P. edulis* (22.7 g) than for *D. asper* (18.4 g; Fig. S1E). Therefore, there were clear differences between the seeds of these two bamboo species.

3.2. Proximate compositions

The proximate compositions (i.e., moisture, ash, crude fiber, fat, protein, and carbohydrate contents) of bamboo, rice, and wheat seeds are listed in Table 1. Moisture is often measured for the food products. Results indicated that seed moisture content was higher for *P. edulis* than for *D. asper*. However, the moisture content of *D. asper* seeds was similar to that of the other cereal seeds. In contrast, *P. edulis* seeds had lower ash content than wheat but had higher ash content than *D. asper* seeds. While *D. asper* and rice seeds had similar ash contents.

Crude fiber is present in a range of foods, including various seeds. In current study, seed crude fiber was higher for *P. edulis* and *D. asper* (3.92 and 4.45 g/100 g, respectively) than for rice and wheat ($P < 0.05$). Therefore, bamboo seeds may thus be good source of dietary fiber for maintaining human health. Higher intake of cereal fiber has been associated with a lower risks of diabetes, constipation, and colorectal cancer (Willett et al., 2002).

Fat content was the lowest for *P. edulis* seeds. While *D. asper* seeds had the similar fat content to those of rice and wheat seeds. *P. edulis* seeds possessed more protein than rice and wheat seeds ($P < 0.05$). Similarly, the protein content of *D. asper* seeds was higher than that of rice and wheat seeds, with the exception of the seeds from wheat cultivar Shi4185. Bamboo seeds may thus be included in food formulations as protein source.

Seeds carbohydrate content was the highest for rice, followed by wheat, *D. asper*, and *P. edulis*. The comparison of the proximate compositions indicated that bamboo seeds may be a useful source of dietary crude fiber and protein.

3.3. Sugar and soluble protein compositions

In addition to analyzing the seed carbohydrate and protein contents, we also compared the reducing sugar, starch, total sugar, and soluble protein contents of bamboo, rice, and wheat seeds. The reducing sugar content was lower for bamboo seeds than for rice and wheat seeds (Table 2), but the starch content of bamboo seeds was higher than that of wheat seeds, but lower than that of rice seeds. The total sugar content (i.e., all monosaccharides and disaccharides) was the highest for the rice seeds, followed by *P. edulis* seeds, *D. asper* seeds, and wheat seeds, with no significant difference between *D. asper* and wheat seeds. Unlike the crude protein content, the soluble protein content represents a relatively small proportion of the total protein content. The data revealed the soluble protein content of bamboo seeds was significantly higher than that of rice seeds, but significantly lower than that of wheat seeds.

Starch is predominant edible carbohydrate of cereals among dietary carbohydrates, (Cornell, 2012). Starch is usually deposited in the endosperm as granules which act as an energy source by the germinating seeds. Starch is the major source of metabolic energy in humans (Li et al., 2017). In present study, bamboo seeds depicted more starch than wheat seeds, implying that consuming bamboo seeds as food may provide the human body with sufficient energy for required cellular processes and activities.

Table 1
Proximate composition in seeds of bamboo, rice and wheat.

	Bamboo		Rice			Wheat		
	P. edulis	*D. asper*	Jiayou5	Fengliangyou4	Liangyoupeijiu	Kenong199	Shi4185	Jimai325
Moisture(g/100 g)	$8.74^{a} \pm 0.59$	$7.79^{bc} \pm 0.23$	$7.78^{bc} \pm 0.89$	$7.55^{bc} \pm 0.58$	$7.33^{c} \pm 0.13$	$7.95^{b} \pm 0.17$	$7.85^{bc} \pm 0.31$	$7.58^{bc} \pm 0.98$
Ash(g/100 g)	$1.51^{c} \pm 0.07$	$1.22^{de} \pm 0.02$	$1.27^{d} \pm 0.03$	$1.22^{de} \pm 0.02$	$1.19^{e} \pm 0.02$	$1.62^{b} \pm 0.02$	$1.95^{a} \pm 0.04$	$1.64^{b} \pm 0.06$
Crude fiber(g/100 g)	$3.92^{b} \pm 0.12$	$4.45^{a} \pm 0.42$	$2.73^{cd} \pm 0.12$	$2.46^{d} \pm 0.09$	$2.64^{cd} \pm 0.24$	$2.72^{cd} \pm 0.12$	$2.81^{cd} \pm 0.04$	$2.96^{c} \pm 0.15$
Fat(g/100 g)	$2.33^{d} \pm 0.12$	$2.52^{bcd} \pm 0.16$	$2.72^{ab} \pm 0.15$	$2.64^{bc} \pm 0.13$	$2.92^{a} \pm 0.11$	$2.46^{cd} \pm 0.07$	$2.66^{bc} \pm 0.09$	$2.73^{ab} \pm 0.12$
Protein(g/100 g)	$17.79^{a} \pm 0.28$	$12.99^{c} \pm 0.16$	$8.33^{g} \pm 0.22$	$9.23^{f} \pm 0.05$	$10.63^{e} \pm 0.05$	$11.69^{d} \pm 0.18$	$14.28^{b} \pm 0.18$	$11.52^{d} \pm 0.22$
Carbohydrates(g/100 g)	$65.71^{e} \pm 0.22$	$71.03^{d} \pm 0.24$	$77.17^{a} \pm 0.56$	$76.91^{a} \pm 0.4$	$75.29^{b} \pm 0.12$	$73.56^{c} \pm 0.06$	$70.45^{d} \pm 0.39$	$73.56^{c} \pm 0.44$

Results are represented as mean ± standard deviation (n = 3). Statistical comparison was performed by one-way ANOVA, followed by Duncan's test based on independent replications. The mean values with different lower-case letters indicate significant difference at $p < 0.05$.

Table 2
Sugar and soluble protein content in seeds of bamboo, rice and wheat.

	Bamboo		Rice			Wheat		
	P. edulis	*D. asper*	Jiayou5	Fengliangyou4	Liangyoupeijiu	Kenong199	Shi4185	Jimai325
Reducing sugar(g/100 g)	$0.31^{f} \pm 0.01$	$0.52^{e} \pm 0.02$	$0.78^{d} \pm 0.03$	$1.53^{a} \pm 0.05$	$0.19^{g} \pm 0.01$	$0.86^{c} \pm 0.01$	$0.89^{c} \pm 0.02$	$0.96^{b} \pm 0.02$
Starch(g/100 g)	$60.51^{b} \pm 1.47$	$60.82^{b} \pm 0.72$	$68.12^{a} \pm 0.79$	$66.95^{a} \pm 0.54$	$67.9^{a} \pm 0.5$	$52.54^{d} \pm 0.69$	$54.62^{c} \pm 0.02$	$53.64^{cd} \pm 0.39$
Total Sugar(g/100 g)	$63.23^{b} \pm 0.74$	$62.04^{c} \pm 0.44$	$70.81^{a} \pm 0.27$	$70.64^{a} \pm 0.59$	$70.71^{a} \pm 0.41$	$62.46^{bc} \pm 0.84$	$58.91^{d} \pm 0.43$	$61.33^{c} \pm 1.04$
Soluble protein(g/100 g)	$1.34^{d} \pm 0.12$	$1.61^{c} \pm 0.05$	$1.02^{f} \pm 0.04$	$1.17^{e} \pm 0.04$	$1.04^{f} \pm 0.07$	$2.53^{a} \pm 0.08$	$2.29^{b} \pm 0.06$	$2.43^{a} \pm 0.06$

Results are represented as mean ± standard deviation (n = 3). Statistical comparison was performed by one-way ANOVA, followed by Duncan's test based on independent replications. The mean values with different lower-case letters indicate significant difference at $p < 0.05$.

3.4. Phytochemical compositions and mineral element concentrations

Phytic acid ((2,3,4,5,6-pentaphosphonooxycyclohexyl) dihydrogen phosphate) is recognized as an anti-nutritional factor (Vats & Banerjee, 2004). This study revealed that the phytic acid content was significantly lower in *P. edulis* and *D. asper* seeds (1.99 and 1.76 mg/g, respectively) than in rice and wheat seeds ($P < 0.05$; Table 3). However, the flavonoid content was much higher in *P. edulis* seeds than in *D. asper*, rice, and wheat seeds. In addition, the polyphenol content of *P. edulis* seeds was higher than that of rice seeds, but lower than that of wheat seeds, whereas the polyphenol content of *D. asper* seeds was much lower than that of wheat seeds, but similar to that of rice seeds.

Phytic acid being anti-nutritional factor, decreases the bioavailability of micronutrients (Gupta et al., 2015). Therefore, a low seed phytic acid content is likely conducive to the uptake of micronutrients by humans. In this study, it was found that phytic acid content of *P. edulis* seeds was 24% and 54% of those of rice and wheat seeds, respectively. Phytic acid content of *D. asper* seeds was 21% and 48% of those of rice and wheat seeds, respectively. Hence, the chelation of micronutrients by phytic acid is likely less extensive in bamboo seeds than in wheat and rice seeds, suggesting micronutrient bioavailability is greater for bamboo seeds than for the other seeds. Notably, low levels of phytic acid have beneficial effects on human health (e.g., decreasing the risk of cancer and maintaining appropriate blood glucose, plasma cholesterol, and triglyceride levels) (Gemede & Ratta, 2014). Therefore, bamboo seeds may be an ideal food ingredient for promoting human health because of their micronutrient bioavailability and relatively low phytic acid contents. Moreover, the flavonoid content of *P. edulis* seeds (8.67 mg/g) was 5.7- and 10.4-times higher than that of rice and wheat seeds, respectively. Flavonoids are important antioxidants that help prevent various diseases, such as cancer, while also minimizing the risk of platelet hyperactivation, pain, and thrombosis (Vazhappilly et al., 2019). Therefore, the high flavonoid content of *P. edulis* seeds may be exploited to produce a functional food product.

Table 3
Phytochemicals and mineral elements content in seeds of bamboo, rice and wheat.

	Bamboo		Rice			Wheat		
	P. edulis	*D. asper*	Jiayou5	Fengliangyou4	Liangyoupeijiu	Kenong199	Shi4185	Jimai325
Phytochemicals content								
Phytic acid (mg/g)	$1.99^{e} \pm 0.06$	$1.76^{e} \pm 0.19$	$9.06^{a} \pm 0.24$	$8.16^{b} \pm 0.37$	$7.66^{c} \pm 0.45$	$3.7^{d} \pm 0.06$	$3.55^{d} \pm 0.21$	$3.67^{d} \pm 0.14$
Polyphenols (mg/ g)	$4.05^{c} \pm 0.07$	$1.59^{d} \pm 0.02$	$1.26^{e} \pm 0.02$	$1.57^{d} \pm 0.01$	$1.46^{de} \pm 0.03$	$5.05^{a} \pm 0.19$	$4.31^{b} \pm 0.24$	$3.86^{c} \pm 0.18$
Flavonoids(mg/g)	$8.67^{a} \pm 0.23$	$1.16^{d} \pm 0.03$	$1.61^{c} \pm 0.04$	$1.79^{b} \pm 0.03$	$1.18^{d} \pm 0.09$	$0.83^{e} \pm 0.03$	$0.8^{e} \pm 0.05$	$0.87^{e} \pm 0.02$
Minerals								
Mg(μg/g)	$1203.1^{d} \pm 41.7$	$974.1^{e} \pm 51.1$	$1483.8^{c} \pm 11.9$	$1423.6^{c} \pm 53.8$	$1611.1^{b} \pm 5.0$	$1604.1^{b} \pm 11.2$	$1872.6^{a} \pm 24.5$	$1601.2^{b} \pm 59.6$
P(μg/g)	$4327.6^{b} \pm 140.4$	$3127.3^{c} \pm 231.2$	$4399.0^{b} \pm 32.6$	$4120.5^{b} \pm 20.6$	$4192.1^{b} \pm 160.8$	$4692.9^{ab} \pm 267.1$	$5019.2^{a} \pm 85.1$	$4409.5^{b} \pm 52.8$
K(μg/g)	$4538.7^{b} \pm 137.5$	$3331.0^{c} \pm 390.9$	$3631.1^{c} \pm 252.4$	$3485.5^{c} \pm 150.1$	$3037.2^{c} \pm 156.2$	$4503.5^{b} \pm 47.2$	$5452.8^{a} \pm 214.3$	$4984.7^{ab} \pm 209.2$
Ca(μg/g)	$38.5^{c} \pm 5.8$	$12.1^{e} \pm 0.8$	$18.1^{d} \pm 1.6$	$12.4^{e} \pm 0.5$	$15.8^{de} \pm 0.2$	$62.7^{a} \pm 4.0$	$54.7^{b} \pm 0.5$	$59.9^{a} \pm 3.6$
Mn(μg/g)	$83.7^{a} \pm 5.9$	$40.5^{b} \pm 1.7$	$13.8^{e} \pm 1.1$	$38.0^{b} \pm 4.1$	$27.2^{d} \pm 0.6$	$39.7^{b} \pm 2.0$	$34.8^{c} \pm 0.9$	$35.8^{bc} \pm 1.0$
Fe(μg/g)	$45.3^{b} \pm 18.8$	$60.7^{a} \pm 9.3$	$13.2^{e} \pm 0.1$	$12.2^{e} \pm 0.1$	$11.7^{e} \pm 0.5$	$37.9^{c} \pm 3.1$	$26.8^{d} \pm 0.2$	$26.2^{d} \pm 1.9$
Cu(μg/g)	$19.4^{a} \pm 0.7$	$12.2^{b} \pm 1.1$	$3.8^{c} \pm 0.3$	$1.8^{d} \pm 0.3$	$2.5^{d} \pm 0.3$	$4.5^{c} \pm 0.1$	$4.1^{c} \pm 0.1$	$4.2^{c} \pm 0.2$
Zn(μg/g)	$83.9^{a} \pm 4.1$	$56.7^{b} \pm 7.2$	$30.8^{d} \pm 2.0$	$23.5^{e} \pm 1.6$	$24.9^{e} \pm 0.2$	$35.1^{c} \pm 2.1$	$34.9^{c} \pm 0.1$	$38.4^{c} \pm 1.1$

Results are represented as mean ± standard deviation (n = 3). Statistical comparison was performed by one-way ANOVA, followed by Duncan's test based on independent replications. The mean values with different lower-case letters indicate significant difference at $p < 0.05$.

The mineral elements in bamboo seeds, such as magnesium (Mg), potassium (K), calcium (Ca), manganese (Mn), iron (Fe), copper (Cu), and zinc (Zn) were determined and compared with those of rice and wheat seeds (Table 4). Bamboo seeds had lower Mg, P, K, and Ca contents than in rice and wheat seeds, whereas the opposite trend was detected for the Mn, Fe, Cu, and Zn contents. Micronutrient deficiencies, especially Fe and Zn, affect more than two billion people worldwide (Khatibzadeh et al., 2016). Therefore, the dietary uptake of Fe and Zn (e.g., from dairy products) will need to increase. In this study, bamboo seeds were revealed to contain relatively large amounts of Fe and Zn, suggestive of their utility for research on the biofortification of food crops to increase Fe and Zn levels. Moreover, an additional benefit of the low phytic acid contents in bamboo seeds is that the inhibitory effects of phytic acid on Fe and Zn are probably lower in bamboo seeds than in rice or wheat seeds. We speculate that a relatively low concentration of inhibitory factors contributes to the high Fe and Zn contents and bioavailability in bamboo seeds. However, the bioavailability of these mineral elements in bamboo seeds will need to be more comprehensively investigated in future studies.

3.5. Amino acid profiles

Bamboo seeds had high protein contents, however protein quantity is not necessarily correlated with protein quality. The amino acids in seeds were thus identified and quantified. A total of 17 amino acids were identified (aspartic acid, cysteine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, lysine, histidine, threonine, serine, glutamic acid, glycine, alanine, arginine, and proline) in bamboo, rice, and wheat seeds using an amino acid analyzer (Table 4). Amino acid contents varied among the seeds. For most of the identified amino acids, the contents were generally the highest for bamboo seeds, followed by wheat and rice seeds. More specifically, the glutamic acid content was highest in all seeds (1.64–5.29 g/100 g), followed by the leucine (0.84–1.60 g/100 g) and aspartic acid (0.74–1.73 g/100 g) contents. The seeds of both bamboo species contained 10 essential amino acids (aspartic acid, cysteine, valine, methionine, isoleucine, leucine, tyrosine, phenylalanine, lysine, and histidine), of which aspartic acid, valine, methionine, and lysine were detected at significantly higher levels in bamboo seeds than in rice and wheat seeds. The lysine content was almost 2-folds higher in *P. edulis* seeds than in rice and wheat seeds. This is noteworthy because lysine is one of the limiting amino acids in most cereals. The contents of the other six essential amino acids were also significantly higher in *P. edulis* seeds than in rice and wheat seeds. The contents of these six essential amino acids were significantly higher in *D. asper* seeds than in rice seeds, but the comparison with wheat seeds indicated they were slightly higher in seeds of wheat cultivar Shi4185 than in *D. asper* seeds. Some essential amino acids from daily human diet lower the risk of cancer and cardiovascular diseases (Krishnan & Jez, 2018).

Among seven non-essential amino acids identified in *P. edulis* and *D. asper* seeds, threonine, glycine, alanine, and arginine were detected at significantly higher levels in bamboo seeds than in rice and wheat seeds. The abundance of glutamic acid and proline in bamboo seeds was higher than that in rice seeds, but lower than that in wheat seeds. Serine content was higher in *P. edulis* seeds than in rice and wheat seeds, however it was lower in *D. asper* seeds was lower than that in wheat seeds and higher than that in rice seeds. These findings imply that bamboo seeds are a good source of essential amino acids.

3.6. Water-soluble B vitamin compositions

The seeds from some edible plants and cereals are an important source of most of the B vitamins, including water-soluble vitamins thiamin, riboflavin, and niacin (McKevith, 2004). In the current study, six water-soluble B vitamins (thiamin, riboflavin, niacin, pyridoxine, folate, and pantothenic acid) were screened and analyzed using an ultra-high performance liquid chromatography system. With the exception of folate, these vitamins were detected in the bamboo, rice, and wheat seeds (Table 5). The thiamin and niacin contents were higher in *D. asper* seeds than in *P. edulis*, rice, and wheat seeds. The pantothenic acid content was significantly higher in *P. edulis* seeds than in *D. asper*, rice, and wheat seeds. The pyridoxine content was the highest in wheat seeds, followed by bamboo and rice seeds. The riboflavin content was much higher in *P. edulis* seeds than in most of rice and wheat seeds. In contrast, *D. asper* and wheat seeds had similar riboflavin contents. Vitamins are important for human health because of their crucial roles in enzymatic and metabolic processes (Langer & Lodge, 2014). For example, thiamin is essential for energy metabolism, while riboflavin promotes the reduction of fatty acids and enhances choline catabolism, while also positively affecting ocular and skin health (Al-Farga et al., 2016). In the present study, some vitamins like thiamin and niacin were less abundant in *P. edulis* seeds than in rice and wheat seeds. However, this difference likely will not affect the utility of bamboo seeds as a source of food. Humans generally obtain sufficient amounts of water-soluble B vitamins through their diet, which is why water-soluble B vitamin deficiencies are rare (Lebiedzińska & Szefer, 2006). For example, thiamin deficiencies

Table 4
Total amino acids content in seeds of bamboo, rice and wheat.

Amino Acid (g/100 g)	Bamboo		Rice			Wheat		
	P. edulis	*D. asper*	Jiayou5	Fengliangyou4	Liangyoupeijiu	Kenong199	Shi4185	Jimai325
aspartic acid	$1.73^{a} \pm 0.01$	$1.27^{b} \pm 0.03$	$0.82^{ef} \pm 0.02$	$0.92^{d} \pm 0.02$	$1.14^{c} \pm 0.02$	$0.8^{f} \pm 0.01$	$0.86^{e} \pm 0.04$	$0.74^{g} \pm 0.02$
threonine	$0.7^{a} \pm 0$	$0.5^{b} \pm 0.02$	$0.34^{f} \pm 0.01$	$0.37^{e} \pm 0.01$	$0.45^{c} \pm 0.01$	$0.42^{d} \pm 0.01$	$0.49^{b} \pm 0.02$	$0.42^{d} \pm 0.01$
serine	$0.78^{a} \pm 0.02$	$0.55^{c} \pm 0.06$	$0.45^{d} \pm 0.02$	$0.46^{d} \pm 0.03$	$0.6^{bc} \pm 0.01$	$0.59^{bc} \pm 0.04$	$0.74^{a} \pm 0.02$	$0.62^{b} \pm 0.02$
glutamic acid	$3.68^{d} \pm 0$	$2.27^{e} \pm 0.07$	$1.64^{g} \pm 0.04$	$1.87^{f} \pm 0.04$	$2.25^{e} \pm 0.03$	$3.99^{c} \pm 0.09$	$5.29^{a} \pm 0.25$	$4.19^{b} \pm 0.04$
glycine	$0.93^{a} \pm 0.01$	$0.69^{b} \pm 0.02$	$0.42^{e} \pm 0.01$	$0.47^{d} \pm 0.01$	$0.57^{c} \pm 0.01$	$0.58^{c} \pm 0.01$	$0.69^{b} \pm 0.04$	$0.59^{c} \pm 0.02$
alanine	$1.15^{a} \pm 0.01$	$0.82^{b} \pm 0.02$	$0.55^{e} \pm 0.01$	$0.6^{d} \pm 0.01$	$0.74^{c} \pm 0.01$	$0.54^{e} \pm 0.01$	$0.61^{d} \pm 0.03$	$0.53^{e} \pm 0.01$
cysteine	$0.23^{a} \pm 0.01$	$0.18^{c} \pm 0.01$	$0.13^{d} \pm 0$	$0.14^{d} \pm 0$	$0.14^{d} \pm 0$	$0.19^{c} \pm 0.01$	$0.2^{b} \pm 0.02$	$0.18^{c} \pm 0.01$
valine	$1.18^{a} \pm 0.01$	$0.87^{b} \pm 0.02$	$0.61^{e} \pm 0.02$	$0.66^{d} \pm 0.01$	$0.82^{c} \pm 0.01$	$0.68^{d} \pm 0.01$	$0.78^{c} \pm 0.04$	$0.67^{d} \pm 0.01$
methionine	$0.5^{a} \pm 0$	$0.31^{b} \pm 0.02$	$0.27^{cd} \pm 0.01$	$0.25^{d} \pm 0.02$	$0.3^{bc} \pm 0.02$	$0.26^{d} \pm 0$	$0.28^{cd} \pm 0.04$	$0.22^{e} \pm 0$
isoleucine	$0.79^{a} \pm 0.01$	$0.56^{c} \pm 0.02$	$0.4^{f} \pm 0.01$	$0.43^{e} \pm 0$	$0.54^{cd} \pm 0.01$	$0.52^{cd} \pm 0.01$	$0.6^{b} \pm 0.04$	$0.51^{d} \pm 0.01$
leucine	$1.6^{a} \pm 0.01$	$1.13^{c} \pm 0.03$	$0.84^{f} \pm 0.02$	$0.94^{e} \pm 0.01$	$1.16^{c} \pm 0.02$	$1.04^{d} \pm 0.01$	$1.27^{b} \pm 0.08$	$1.04^{d} \pm 0.02$
tyrosine	$0.8^{a} \pm 0$	$0.54^{c} \pm 0.02$	$0.49^{d} \pm 0.01$	$0.53^{c} \pm 0.01$	$0.63^{b} \pm 0.01$	$0.55^{c} \pm 0.01$	$0.64^{b} \pm 0.04$	$0.55^{c} \pm 0.01$
phenylalanine	$1.29^{a} \pm 0.01$	$0.89^{c} \pm 0.03$	$0.62^{g} \pm 0.01$	$0.67^{f} \pm 0$	$0.81^{d} \pm 0.01$	$0.75^{e} \pm 0.01$	$0.94^{b} \pm 0.06$	$0.75^{e} \pm 0.01$
lysine	$0.81^{a} \pm 0.01$	$0.67^{b} \pm 0.02$	$0.35^{f} \pm 0.01$	$0.39^{e} \pm 0.01$	$0.48^{c} \pm 0$	$0.44^{d} \pm 0$	$0.47^{c} \pm 0.03$	$0.43^{d} \pm 0.01$
histidine	$0.49^{a} \pm 0.01$	$0.37^{c} \pm 0.01$	$0.25^{f} \pm 0.01$	$0.28^{e} \pm 0$	$0.33^{d} \pm 0$	$0.34^{d} \pm 0$	$0.41^{b} \pm 0.02$	$0.34^{d} \pm 0.01$
arginine	$1.85^{a} \pm 0$	$1.28^{b} \pm 0.03$	$0.74^{f} \pm 0.02$	$0.86^{d} \pm 0.02$	$1.05^{c} \pm 0.01$	$0.69^{g} \pm 0.01$	$0.8^{e} \pm 0.04$	$0.69^{g} \pm 0.02$
proline	$0.73^{d} \pm 0.01$	$0.5^{ef} \pm 0.01$	$0.35^{g} \pm 0.01$	$0.41^{fg} \pm 0.05$	$0.54^{e} \pm 0.01$	$1.19^{c} \pm 0.08$	$1.6^{a} \pm 0.16$	$1.32^{b} \pm 0.02$

Results are represented as mean ± standard deviation (n = 3). Statistical comparison was performed by one-way ANOVA, followed by Duncan's test based on independent replications. The mean values with different lower-case letters indicate significant difference at $p < 0.05$.

Table 5
Water-soluble vitamins content in seeds of bamboo, rice and wheat.

	Bamboo		Rice			Wheat		
	P. edulis	*D. asper*	Jiayou5	Fengliangyou4	Liangyoupeijiu	Kenong199	Shi4185	Jimai325
Thiamin(mg/100 g)	$0.16^{d} \pm 0.01$	$0.33^{a} \pm 0.01$	$0.22^{c} \pm 0.01$	$0.16^{d} \pm 0.01$	$0.21^{c} \pm 0$	$0.29^{b} \pm 0.01$	$0.33^{a} \pm 0.01$	$0.29^{b} \pm 0.01$
Niacin(mg/100 g)	ND	$0.54^{a} \pm 0.01$	$0.28^{e} \pm 0.01$	$0.19^{g} \pm 0.01$	$0.23^{f} \pm 0.01$	$0.33^{c} \pm 0.01$	$0.41^{b} \pm 0.01$	$0.3^{d} \pm 0.01$
Pyridoxine(mg/100 g)	$0.18^{c} \pm 0.01$	$0.23^{b} \pm 0$	$0.16^{d} \pm 0.01$	$0.11^{e} \pm 0$	$0.1^{e} \pm 0.01$	$0.25^{a} \pm 0.01$	$0.26^{a} \pm 0$	$0.25^{a} \pm 0.01$
Panthotenic acid(mg/100 g)	$3.89^{a} \pm 0.02$	$1.78^{c} \pm 0.02$	$2.03^{b} \pm 0.01$	$1.64^{d} \pm 0.01$	$1.79^{c} \pm 0.01$	$1.09^{e} \pm 0.01$	$0.99^{f} \pm 0.01$	$1.1^{e} \pm 0.01$
Folate(mg/100 g)	ND	ND	ND	ND	ND	ND	ND	ND
Riboflavin(mg/100 g)	$0.21^{b} \pm 0.02$	$0.12^{e} \pm 0$	$0.33^{a} \pm 0.01$	$0.19^{c} \pm 0$	$0.17^{d} \pm 0.01$	$0.1^{f} \pm 0$	$0.11^{ef} \pm 0$	$0.13^{e} \pm 0.01$

Results are represented as mean ± standard deviation (n = 3). Statistical comparison was performed by one-way ANOVA, followed by Duncan's test based on independent replications. The mean values with different lower-case letters indicate significant difference at $p < 0.05$.
ND: not detected.

are restricted to people who are fed intravenously without any thiamin supplementation (Lebiedzińska & Szefer, 2006). The similarity in the water-soluble B vitamin contents among bamboo, rice, and wheat seeds suggests bamboo seeds may be an alternative to rice and wheat grains as a source of B vitamins.

3.7. Fatty acid compositions

Fatty acids are the minor component of most cereal grains, however, some are essential for human health (Solà Marsiñach & Cuenca, 2019). Fatty acid content was analyzed for bamboo, rice, and wheat seeds using a gas chromatography system. The five main fatty acids identified in the seeds and then quantified are listed in Table 6. Oleic acid, linoleic acid and linolenic acid are unsaturated fatty acids, whereas palmitic acid and stearic acid are saturated fatty acids. Overall, the seed fatty acid contents were the highest in rice, followed by wheat and bamboo. Linoleic acid was the predominant fatty acid (36.09%–63.56%) in all tested seeds. The other relatively abundant fatty acids were oleic acid (24.75%–36.74%), palmitic acid (18.21%–22.56%), stearic acid (3.18%–4.94%), and linolenic acid (1.79%–2.92%) in bamboo and rice seeds and palmitic acid (16.99%–18.61%), oleic acid (12.21%–12.93%), linolenic acid (3.54%–4.07%), and stearic acid (2.98%–3.39%) in wheat seeds. The comparison of individual fatty acids in the seeds revealed that the stearic acid percentage was higher in bamboo seeds than in rice and wheat seeds, but the palmitic acid percentage was similar in all seeds. For the other three fatty acids, the percentages were all much lower in bamboo seeds than in rice and wheat seeds. The calculated unsaturated and saturated fatty acid percentages indicated that the unsaturated fatty acid percentage was much higher than the saturated fatty acid percentage in all seeds. Unsaturated fatty acids decrease the coronary heart disease risk (Dorni et al., 2018). Some unsaturated fatty acids, such as linoleic acid, are essential for human health and are not synthesized by the human body (Dorni et al., 2018). Therefore, these fatty acids must be acquired from the daily diet. It was determined that the unsaturated fatty acid content of bamboo seeds was like those of rice and wheat seeds, indicating rice and wheat grains in the human diet may be replaced by bamboo seeds. Bamboo seeds are rich in nutrients, however few studies encompass the production and bamboo seeds harvesting, belonging to different species and different regions. It is estimated that only 50 kg seeds per ha are collected from two wild Madagascar bamboos species (Janzen, 1976), whereas seeds can harvest more than 86 kg per bamboo culm of bamboo species such as *B. arundinaceae*, original from India (Gadgil & Prasad, 1983). Bamboo seeds price is specie- and region-dependent, however it is higher than common cereals such as rice and wheat.

4. Conclusion

Bamboo rice is consumed as food, but there is a lack of basic information regarding its nutritional value and chemical properties. To the best of our knowledge, this study is the first to comprehensively evaluate the nutritional properties of two typical bamboo rice species and compare bamboo seeds with rice and wheat seeds in terms of proximate and mineral element compositions, water-soluble B vitamins, amino

Table 6
Fatty acids composition in seeds of bamboo, rice and wheat.

	Bamboo		Rice			Wheat		
	P. edulis	*D. asper*	Jiayou5	Fengliangyou4	Liangyoupeijiu	Kenong199	Shi4185	Jimai325
Fatty Acid content (% of sample)	$2.11^{f} \pm 0.05$	$1.97^{g} \pm 0.03$	$3.67^{a} \pm 0.16$	$3.72^{a} \pm 0.18$	$3.47^{b} \pm 0.06$	$2.45^{d} \pm 0.14$	$2.6^{c} \pm 0.11$	$2.3^{e} \pm 0.04$
Fatty Acid composition (% of total fatty acids)								
Palmitic (C16:0)	$18.20^{b} \pm 0.52$	$22.12^{a} \pm 1.41$	$18.8^{b} \pm 0.71$	$22.56^{a} \pm 1.01$	$22.27^{a} \pm 0.31$	$16.99^{c} \pm 1.61$	$17.89^{bc} \pm 0.9$	$18.61^{b} \pm 0.69$
Stearic (C18:0)	$4.32^{b} \pm 0.1$	$4.94^{a} \pm 0.43$	$3.22^{de} \pm 0.05$	$3.8^{c} \pm 0.19$	$3.18^{e} \pm 0.05$	$3.24^{de} \pm 0.26$	$2.98^{f} \pm 0.06$	$3.39^{d} \pm 0.08$
Oleic (C18:1)	$24.75^{e} \pm 0.54$	$34.64^{b} \pm 0.52$	$36.74^{a} \pm 1.76$	$31.34^{c} \pm 1.3$	$29.2^{d} \pm 0.55$	$12.66^{f} \pm 1.94$	$12.93^{f} \pm 0.9$	$12.21^{f} \pm 0.55$
Linoleic (C18:2)	$49.81^{b} \pm 1.49$	$36.09^{e} \pm 0.23$	$39.45^{d} \pm 1.76$	$40.36^{d} \pm 1.71$	$43^{c} \pm 0.88$	$63.56^{a} \pm 2.48$	$62.16^{a} \pm 2.26$	$61.72^{a} \pm 1.25$
linolenic (C18:3)	$2.92^{c} \pm 0.1$	$2.21^{d} \pm 0.13$	$1.79^{e} \pm 0.06$	$1.93^{e} \pm 0.07$	$2.35^{d} \pm 0.06$	$3.54^{b} \pm 0.23$	$4.05^{a} \pm 0.24$	$4.07^{a} \pm 0.16$
Total unsaturated fatty acids	$77.48^{ab} \pm 1.99$	$72.94^{c} \pm 0.97$	$77.99^{ab} \pm 3.73$	$73.64^{c} \pm 3.54$	$74.55^{bc} \pm 1.47$	$79.77^{a} \pm 3.88$	$79.13^{a} \pm 3.24$	$78^{a} \pm 1.37$
Total saturated fatty acids	$22.52^{c} \pm 0.64$	$27.06^{a} \pm 1.53$	$22.01^{cd} \pm 0.8$	$26.36^{ab} \pm 1.34$	$25.45^{b} \pm 0.33$	$20.23^{e} \pm 1.8$	$20.87^{de} \pm 1.13$	$22^{c} \pm 0.48$

Results are represented as mean ± standard deviation (n = 3). Statistical comparison was performed by one-way ANOVA, followed by Duncan's test based on independent replications. The mean values with different lower-case letters indicate significant difference at $p < 0.05$.

acid profiles, and fatty acid profiles. The achieved results indicate that most nutritional components are similarly abundant or more abundant in bamboo seeds compared with rice and wheat grains. Bamboo rice is thus a source of essential nutrients and potential substitute of rice and wheat. Furthermore, bamboo seeds are rich in dietary fiber, proteins, mineral elements, and flavonoids. The composition reflects its potential utility as ingredient of functional foods and an alternative source of dietary nutrients.

CRediT authorship contribution statement

Zhijian Chen: Investigation, Formal analysis, Writing – original draft. **Xianyu Pan:** Investigation, Formal analysis, Writing – original draft. **Lin Hu:** Conceptualization, Writing – original draft. **Haibao Ji:** Conceptualization, Funding acquisition. **Xuejun Yu:** Conceptualization, Funding acquisition. **Ji Feng Shao:** Conceptualization, Writing – original draft, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.fochx.2023.100723.

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