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Review

Bioactive compounds in bamboo shoots: health benefits and prospects for developing functional foods

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Summary Juvenile bamboo shoots have long been used as food and in traditional medicine in many Asian countries, but scientific evidences of its health benefits have been highlighted recently. According to ancient Chinese medicinal books, the consumption of young shoots helps in improving digestion, relieving hypertension, sweating, preventing cardiovascular diseases and cancer. The young shoots are delicious and rich in nutrient components such as proteins, carbohydrates, minerals and vitamins and bioactive compounds. The health benefits of the young shoots are attributed to the presence of bioactive compounds mainly phenols, phytosterols and dietary fibres, which play a potential role in health promotion and providing protection against many chronic and degenerative diseases. Phenolic compounds in bamboos have multiple biological effects such as antioxidation, anti-ageing, antifatigue, antimicrobial and prevention of cardiovascular diseases. Dietary fibres and phytosterols have a beneficial effect on lipid profile and bowel function and reduce total serum cholesterol and low-density lipoprotein cholesterol level. This study discusses the bioactive compounds in bamboo shoots and how, due to its nutritive value and health benefits, the shoots can be utilised as an ingredient in the development of functional foods.

Keywords Bamboo shoots, dietary fibres, functional foods, phenols, phytosterols.

Introduction

Since the last decade, food is no longer viewed as a means to satisfy hunger and provide necessary nutrients to meet metabolic demands, but also to prevent nutrition-related diseases and improve physical and mental well-being (Betoret *et al*., 2011). Research carried out in the last two decades has correlated diet and certain diseases, showing the possibility of food to support or even improve our health. These types of food have been generically named functional foods and represent one of the most interesting areas of research and innovation in the food industry (Bigliardi & Galati, 2013). Specific food constituents called bioactive compounds have been identified which are extra-nutritional constituents occurring in small quantities in foods that provide health benefits beyond the basic nutritional value of the product. Bioactive compounds in plants are produced as secondary metabolites and are known to elicit pharmacological and toxicological effects in humans and animals (Bernhoft, 2010). Examples of beneficial effects of bioactive compounds are as follows: decrease in cholesterol levels, alleviation of lactose intolerance, faster relief from diarrhoea and inhibition of cancer cell proliferation *in vivo* and *in vitro* (Nobili *et al*., 2009; Marette *et al*., 2010). Both the pharmaceutical and food industry are working intensively to characterise natural bioactive compounds, which can be used as drugs and functional food ingredients. Major bioactive compounds such as dietary fibre, phytosterols and phenols have proven to be effective against certain diseases and studies have been conducted in fruits, vegetables, legumes and whole grains, but it is lacking in bamboos. Bamboo shoot, a popular ingredient in South Asian cuisines, is a vegetable rich in bioactive compounds. Although bamboos are extensively used for industrial purposes, the use of young bamboo shoots as a daily food ingredient is confined to only some countries particularly in East and South-East Asian countries. Consumption of shoots is gaining popularity worldwide due to its nutritive value and health benefits (Nirmala *et al*., 2011; Singhal *et al*., 2013).

Bamboos have been intricately associated with humans for its medicinal uses in various parts of the world. In ancient Ayurvedic, Indo-Persian and Tibetan

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system of medicine, the siliceous secretions present in the internodes known variously as 'Tabasheer', 'Banslochan' and 'Bamboo manna' are used for various ailments (Puri, 2003). In China, decoction of the shoots has been used for treating infections, cleaning wounds, maggot-infected sores and ulcers. In Java, sap from shoots is used for curing jaundice (Burkill, 1935). A study conducted by Sangtam *et al.* (2012) on the medicinal plants used by the Naga tribe in Kiphire District, Nagaland, revealed that the young tender shoots of *Bambusa tulda* known locally as 'Huti' are boiled in water and applied on chicken pox and other skin diseases. Bamboo salt prepared by baking salt repeatedly with bamboo shoots in a furnace is used as a detoxifying agent (Liu, 1992). These ancient medical practices were not given much importance due to lack of scientific evidences. Recent studies on the medicinal properties of bamboo leaves and bamboo shoot skin have shown antioxidant, anticancer and antibiotic properties (Tanaka *et al.*, 2011, 2013). The nutritive value of bamboo shoots has been documented by several workers (Kumbhare & Bhargava, 2007; Nirmala *et al.*, 2007, 2008, 2011). Since bamboo shoots are not only rich in nutrients but also contain bioactive compounds (Table 1), they can be used as an ingredient in functional foods (Nirmala & Bisht, 2012) and is discussed below.

Phenolic compounds

Phenolic compounds, products of secondary metabolism, are widespread in plants and have attracted both public and scientific interest because of their health-promoting effects and potential applications as antioxidants and antimicrobial agents (Proestos *et al.*, 2013). They exhibit numerous positive effects beneficial to health such as antioxidant, anti-inflammatory, anti-allergic, antimicrobial, cardioprotective and vasodilating properties (Landete, 2012). Phenols act as antioxidants via different mechanisms, such as scavenging of free radicals, quenching of ROS, inhibition of oxidative enzymes, chelation of transition metals or due to interaction with biomembranes. Antioxidant property is one of the most important features considered for improvement in food nutritional quality. Along with providing possible health benefits, ingredients rich in phenolics are employed as antioxidants in many food systems such as functional foods (Brewer, 2011; Craft *et al.*, 2012).

The functional properties of edible shoots of *Phyllostachys pubescens* and *Phyllostachys nigra* were evaluated from shoot extracts for their antioxidant capacity, antimicrobial activity, angiotensin-converting-enzyme inhibition activity, ascorbic acid and phenolic compound content (Park & Jhon, 2010). Comparison of antioxidant capacities between extracts of bamboo shoots was performed, and antimicrobial test of phenolic compounds on some bacterial and fungal strains was conducted. Of the two species tested, *P. nigra* showed higher extraction yield, antioxidant capacity and ascorbic acid and phenolic compound content than *P. pubescens* (Park & Jhon, 2010). The presence of tannins, steroids, phenols and flavanoids were reported from methanol and ethyl acetate extracts of fermented shoots (Singh *et al.*, 2012). Their therapeutic potential was confirmed by the antimicrobial property of the methanolic extract against 4 bacterial strains *Staphylococcus aureus, Bacillus subtilis, Pseudomonas aeruginosa* and *Escherichia coli* and 3 fungal strains viz. *Aspergillus niger, Candida albicans* and *Fusarum oxyporum*. Dichloromethane extracts prepared from bamboo shoot skins of moso bamboo *Phyllostachys pubescens* have been reported to have antibacterial activity against *Staphylococcus aureus* (Tanaka *et al.*, 2011). Moso bamboo shoot skins have been traditionally used as a preservative to maintain the taste of tea in China and as a packaging material for rice balls and meat in Japan.

Phenolic content was estimated in fresh and processed shoots of four bamboo species, *Bambusa balcooa, B. tulda, D. giganteus* and *D. hamiltonii*. The fresh shoots had 450 mg per 100 g fresh weight, which decreased after boiling. Thus, to retain the antioxidant property and gain health benefits, bamboo shoots should be consumed fresh. The effect of precooking treatments – boiling, soaking in brine solution,

Table 1 Macronutrients, dietary fibre (g per 100 g fresh weight), vitamins, phenols (mg per 100 g fresh weight), phytosterols (g per 100 g dry weight) in the fresh juvenile shoots of some bamboo species

Species	Proteins	Carbohydrates	Starch	Vitamin C	Vitamin E	Dietary Fibre	Phenols	Phytosterols
B. balcooa	2.91 ± 0.02	6.54 ± 0.01	1.54 ± 0.02	2.21 ± 0.01	0.62 ± 0.01	6.75 ± 0.08	191.37 ± 2.62	0.19 ± 0.01
B. tulda	3.69 ± 0.03	6.92 ± 0.04	0.59 ± 0.12	1.42 ± 0.06	0.61 ± 0.14	3.97 ± 0.02	443.97 ± 6.09	0.13 ± 0.01
B. nutans	2.84 ± 0.12	5.47 ± 0.05	0.21 ± 0.02	1.19 ± 0.10	0.47 ± 0.06	2.28 ± 0.01	275.36 ± 24.04	–
D. giganteus	3.11 ± 0.17	5.10 ± 0.04	0.51 ± 0.06	3.28 ± 0.02	0.69 ± 0.03	2.65 ± 0.03	222.40 ± 6.26	0.15 ± 0.08
D. hamiltonii	3.72 ± 0.12	5.50 ± 0.08	0.47 ± 0.03	2.45 ± 0.08	0.71 ± 0.03	3.90 ± 0.03	264.83 ± 6.75	0.19 ± 0.04
D. membranaceus	3.38 ± 0.10	5.40 ± 0.03	0.23 ± 0.04	1.58 ± 0.06	0.65 ± 0.10	2.91 ± 0.06	302.73 ± 18.53	–
D. strictus	2.60 ± 0.07	6.17 ± 0.02	0.31 ± 0.05	2.43 ± 0.11	0.58 ± 0.03	2.26 ± 0.01	271.23 ± 5.64	0.14 ± 0.03

Table 2 Phenolic content in bamboo shoots after various treatments (mg per 100 g fresh weight)

		Processed sample							
		24-h water soaking		30-min boiling		Canned		Fermented	
Species	Fresh sample	Content	Decrease (%)	Content	Decrease (%)	Content	Decrease (%)	Content	Increase (%)
Bambusa balcooa	191.37 ± 2.62	53.07 ± 0.09	72.27	56.83 ± 1.67	70.30	21.37 ± 0.28	88.83	298.53 ± 2.5	56.0
B. tulda	443.97 ± 6.09	58.17 ± 0.09	86.90	120.77 ± 0.72	73.0	67.23 ± 0.67	84.85	641.73 ± 0.90	44.54
Dendrocalamus giganteus	347.27 ± 2.34	187.97 ± 1.26	45.87	182.80 ± 1.19	47.36	80.36 ± 1.10	76.86	891.33 ± 7.45	156.66
D. hamiltonii	505.93 ± 1.68	56.74 ± 0.18	88.79	88.47 ± 0.88	82.51	34.47 ± 1.12	93.19	745.56 ± 1.55	47.36

canning and fermentation on phenolic content of *D. giganteus* was determined (Table 2). The total phenols in the sample were determined using the Folin–Ciocalteau method using gallic acid as the standard (Singleton & Rossi, 1965). In fresh bamboo shoots, the phenolic content ranged from a minimum of 191.37 mg per 100 g in *Bambusa balcooa* to a maximum of 505.93 mg per 100 g in *D. hamiltonii* (Table 2). However, when the fresh shoots were subjected to various processing techniques, such as soaking and boiling in water, canning and fermentation, different effects were seen on the phenol content. The phenol content decreased in all treatments, in some cases drastically, except in fermentation. The maximum decrease was observed in canned bamboo shoots, ranging from 76.86% in *D. giganteus* to 93.19% in *D. hamiltonii*. Amongst the four species, *D. hamiltonii* and *B. balcooa* showed maximum decrease in more than 68% phenol content during processing compared with the fresh samples.

Similar results of variation in phenol content due to preservation and other treatments have also been observed in other plants (Chipurura *et al*., 2010; Cartea *et al*., 2011). However, this tremendous increase and decrease in phenol content due to various preservation methods certainly have opened many avenues to do further research on this aspect. Bamboo shoots with very short shelf life need to be processed for long time preservation. Therefore, it is imperative to evaluate the processing methods that influence antioxidant activity in bamboo shoots and optimise conditions to increase or retain their availability and functionality (Nayak *et al*., 2013).The results indirectly also indicate that fermentation of bamboo shoots is far better than canning with respect to phenol content.

Dietary fibres

Dietary fibre is defined as edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the small human intestine with complete or partial fermentation in the large intestine (Tungland & Meyer, 2002). Due to its characteristic of increasing bulk in the bowel movement, dietary fibre is also called roughage and generally categorised as soluble and insoluble, based on solubility in water. Wheat bran, oat, barley and vegetables are the main source of insoluble fibre, but now bamboo shoots are becoming the best option. Young juvenile shoots of bamboo with very high per cent of fibre is a good source for dietary fibre (Nirmala *et al*., 2009). Bamboo fibre is inert, has zero calories and is a white tasteless powder being used in various food products, such as bakery, meat, milk, sausage, beverages, spices, pasta, mustards, ketchups. (Nirmala *et al*., 2011). The fibre content in bamboo shoots can be classified as nutrient detergent fibre (NDF), which determines the indigestible component of the plant material consisting of hemicelluloses, cellulose and lignin and acid detergent fibre (ADF) primarily representing cellulose and lignin. Sixteen bamboo species were analysed for their fibre content, and it was found that the content ranged from 2.23 to 4.20 g per 100 g fresh weight (Fig. S1). The estimation of dietary fibre was done using the methods given by Goering and Van Soest (1970). *Bambusa kingiana* had the highest fibre content of 4.49 g per 100 g fresh weight. The fibre content of bamboo shoots is higher than most of the commonly consumed vegetables (Nirmala *et al*., 2011). Studies have been conducted to compare the nutrient and fibre content in fresh, fermented and canned shoots in a commercially important bamboo *Dendrocalamus giganteus* (Nirmala *et al*., 2008). It was observed that there is an overall decrease in the nutrient components except dietary fibre content during fermentation and canning.

Dietary fibre is associated with a number of health benefits that includes reducing the risk of cardiovascular diseases, hypertension, diabetes, obesity, cancer and certain gastrointestinal disorders (Anderson *et al*., 2009; Lattimer & Haub, 2010; Brennan *et al*., 2012). The effect of a high- fibre bamboo shoot diet was compared with a fibre-free control on eight women in the age group 21–23 years, and blood biochemical parameters such as glucose, triacylglycerols, total cholesterol,

high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, glutamic-pyruvic transaminase, glutamic-oxaloacetic transaminase and atherogenic index were measured (Park & Jhon, 2009). Serum total cholesterol, low-density lipoprotein cholesterol and the atherogenic index were decreased with the bamboo shoot diet feeding compared with the dietary fibre-free diet. These results indicated that bamboo shoots included in the diet as a fibre source has beneficial effect on lipid profile and bowel function. The hemicellulosic fractions from *Phyllostachys pubescens* stem were studied to promote its potential uses in the food industry (Peng *et al*., 2012).

In addition to the health benefits, dietary fibre also imparts some functional properties to foods; for example, increase water-holding capacity, oil-holding capacity, emulsification and/or gel formation. When incorporated into food such as bakery and dairy products, jams, meats and soups, dietary fibres can modify textural properties, avoid synaeresis, stabilise high fat food and emulsions and improve shelf life (Elleuch *et al*., 2011). Supplementation with dietary fibre can result in fitness promoting foods, low in calories, cholesterol and fat. Several studies investigated the influence of dietary fibre supplementation on the quality of foods containing cereals such as pasta, bread, muffin and extruded snacks (Foschia *et al*., 2013).

Phytosterols

Plant sterols or phytosterols are bioactive components that are present in the nonsaponifiable fraction of plant oils. Structurally, they are similar to cholesterol except for substitutions on the sterol side chain at the C24 position (Jones & AbuMweis, 2009). The efficacy of phytosterols as cholesterol-lowering agents have been clearly observed when incorporated into fat spreads as well as other food matrices. Phytosterols appear not only to play an important role in the regulation of cardiovascular disease but also to exhibit anticancer properties (Jones & AbuMweis, 2009; Woyengo *et al*., 2009).

Phytosterols are present in both fresh and fermented bamboo shoots. Predominant sterols in bamboo shoots have been identified as β-sitosterol, campesterol and stigmasterol. He and Lachance (1998) reported that bamboo shoot can significantly decrease serum total and LDL cholesterol in the rat. The sterol content and composition in different shoot parts (shoot bodies and shoot shells) of four species – *Pleioblastus amarus, Phyllostachys pubescens, P.praecox* and *Dendrocalamus latiflorus* were evaluated using an UPLC-APCI-MS method (Lu *et al*., 2009). Six phytosterols were isolated viz. β-sitosterol, campesterol, stigmasterol, cholesterol, ergosterol and stigmastanol of which β-sitosterol was the major sterol. It was found that different species and harvest seasons could affect the sterol content in the shoots but not the sterol composition. There was a significant difference in the sterol content and composition between the shoot bodies and the shoot shell (Lu *et al*., 2009). There was no correlation between the total sterol content and size (height) in the four species. The highest level of β-sitosterol, campesterol and stigmasterol was found in *P. pubescens, P. amarus and P. praecox,* respectively. However, observation showed that the sterol composition is almost constant and independent of genotypic variation.

The effect of the harvest seasons was also observed on the sterol content and composition in bamboo shoots (Lu *et al*., 2009). The shoots of *P. pubescens* harvested in summer were having less sterol content (195.3 mg per 100 g) than shoots harvested in spring (279.6 mg per 100 g) and winter (226.2 mg per 100 g). The shoot harvested in spring contained the highest level of β-sitosterol (83.33%), those harvested in winter contained the highest level of cholesterol (3.4%), and the shoot harvested in summer contained the highest level of ergasterol (0.86%). These findings suggest that the season for harvesting shoot should be considered to have maximum sterol content in the shoots. It has also been observed that sterol is also available in all those parts of shoots which are discarded, particularly the shoot shell. These findings suggest that the spring shoot shell of *P. pubescens* is a potential source of dietary sterol, which can be generated from industrial waste in the course of processing of bamboo shoots. Phytosterols are precursors of many pharmaceutically important steroid products such as corticosteroids, oral contraceptives and anti-inflammatories, synthetic anabolic steroids and esterogenic hormones (Srivastava, 1990). Thus, succulent bamboo shoots, which are easily available in large quantities, can be used as a source of phytosterols.

Like phenol, phytosterol level is also reported to increase due to fermentation of the succulent bamboo shoots (Table 3). Enrichment of phytosterol was observed in fermented shoots from 0.12% to 0.62% dry weight in *Bambusa balcooa* (Sarangthem & Singh, 2003b) and from 0.19% to 0.44% in *Dendrocalamus hamiltonii* as compared to fresh unfermented shoots (Sarangthem & Singh, 2003a). The increase in the level of phytosterols during fermentation was due to the anaerobic digestion of microorganisms that caused degradation of organic matter and resulted in the enrichment of phytosterols. Fermentation is an excellent procedure to store the highly perishable young shoots in the absence of cold storage or refrigeration especially in rural areas where majority cannot afford canned or frozen foods.

A variety of commercial foods have been enriched with free or esterified phytosterols, spreads being the

first commercial application of phytosterol-enriched food (González-Larena *et al*., 2011).

Bamboo shoots as an ingredient for developing functional foods

In the last decade, food industry has undergone a tremendous change with the main focus being on the development of novel or functional foods. Innovations have been made mainly in the scientific and technological approaches of food processing and packaging such as addition of new food ingredients, new food-processing techniques, innovations in food quality and new packaging methods (Bigliardi & Galati, 2013). Normally, these foods contain different amounts and types of bioactive compounds (Bernal *et al*., 2011). When a bioactive compound is included in a food formulation with a specific purpose, the new product is generally considered as a functional food (Day *et al*., 2009). Examples of functional food products that are currently on the market are drinks, cereals, bakery products, spreads, meat products and eggs amongst others. In recent years, there has been considerable interest in the potential for using natural food components for developing functional foods and bamboo shoots could be one of them. Bamboo shoots are used as fresh, canned and fermented and in preparations of various types of cuisines, juices and beer. The most popularly used and liked are the fresh shoots, and the consumption pattern in most of the countries is traditional, nonstandardised, seasonal and region specific with little value addition (Choudhury *et al*., 2012). The young shoots are perishable and have a very short shelf life of 3–4 days at ambient temperature and are available only during the monsoon season. In India, people are still using the old-age traditional technology for processing and preserving the bamboo shoots and preparing the same food item, which are losing popularity amongst the younger generation. In order to take maximum benefit of this highly nutritive and healthy vegetable, processing techniques to properly preserve the bamboo shoots and value addition, by making different edible products using shoot paste or powder as an ingredient, need to be developed so that they are available during the off season and are consumed by more people with the introduction of new food items. Countries such as China and Japan have developed advanced processing and packaging techniques due to which preserved shoots are available throughout the year. In some countries, the shoots have been used as additives in a variety of health foods, beverages and medicines (Lobovikov, 2003; Nirmala *et al*., 2011). Different value-added products such as nuggets, crackers and chutney from fresh bamboo shoots have been prepared (Pandey *et al*., 2012). Such products cannot only provide bamboo based functional food but also increase the utilisation of bamboo shoots and provide quality product to the consumer when the fresh shoots are not available. Plant sterols have been incorporated into a variety of food products such as margarine, bakery products, fruit juice and ice creams. The major sources of phytosterols for current functional foods and dietary supplements are tall oil and vegetable oil deodoriser distillate, both of which involve refining before use in functional foods. As bamboo shoots are edible, these tedious steps of extraction or refining can be eliminated, and the shoots can be used directly in the form of powder or paste or the phytosterols can be extracted and used as an additive in other food items. The discarded shoot shells or culm sheath from shoot processing units that are rich in nutrients and phytosterols can be used as a functional food ingredient.

Bamboo fibre is a common ingredient in bakery, dairy and meat products. The fibre is available commercially in powdered form under the brand name HodayaFiber, Jelucel, JustFiber, Unicell, Qualicel and Vitacel, and the content of dietary fibre is up to 75%. It is used to enhance the fibre content in various food products such as bread and baked foods, pasta, meat and dairy products breakfast cereals, fruit juices, sauces, shredded cheeses, cookies, snacks, frozen desserts, wafers, ice cream cones. It is also used as a slimming and weight loss food supplement and in medicine. Most of the fibre used as additive in foods is derived from wheat, oats, corn and apples. Bamboo shoots have high fibre content than most commonly consumed fruits and vegetables. Hence, it can be conveniently used as an alternative for extraction of fibres for subsequent use in the food industry. Novel food products have been prepared by mixing the paste prepared from fresh bamboo shoots with wheat flour and making chappaties, snacks, cookies, cakes and buns (Bisht *et al*., 2012). Modern functional foods have dietary components that may provide health benefit beyond basic nutrition, and bamboo shoot is one such food item rich in various bioactive compounds for good health. Considering the nutritive value and presence of health beneficial bioactive compounds, bamboo shoots can be used as an ingredient in powder or paste form to make functional foods. Bamboo is a fast-growing plant in different agro-climatic conditions and can meet the ever-increasing demand of edible fibre by the food industry.

Conclusion

The economic, cultural and scientific development of our society has given rise to a sea change in our food habits and life style. Consequently, a huge interest has

Table 3 Phytosterol content in fresh and fermented bamboo shoots

Species	Sterols type and amount (mg per 100 g)					Total sterols (mg per 100 g)	References
	β-sitosterol	Campesterol	Stigmasterol	β-sitostanol	Campestanol		
Phyllostachys praecox	132.8	13.6–28.6	6.4–13.5	–	–	165.4	Lu *et al.* (2009)
Dendrocalamus latiflorus	89.9	13.6–28.6	6.4–13.5	–	–	112.4	
Pleioblastus amarus	177.8	13.6–28.6	6.4.13.5	–	–	221.0	
Phyllostachys pubescens	233.0	21.0–31.7	9.3–14.2	–	–	279.6	
Dendrocalamus hamiltonii (fresh shoot)	–	–	–	–	–	190.0	Sarangthem & Singh (2003a)
D. hamiltonii (fermented)	–	–	–	–	–	440.0	
Bambusa balcooa (fresh)	–	–	–	–	–	122.0	Sarangthem & Singh (2003b)
B. balcooa (fermented)	–	–	–	–	–	620	

been generated amongst scientists, consumers and the food industry on food that can promote health and well-being. Much focus is being paid on functional and nutraceutical food and the health-promoting factors of such food are due to the presence of bioactive compounds. Bamboo shoots are not only delicious and nutritious, but contain bioactive compounds which are beneficial for health. However, the shoots have short shelf life and for long-term usage and availability, they need to be processed for keeping macronutrients and bioactive compounds intact. In addition to consumption as a vegetable, efforts need to be made to utilise the shoots in making novel food products. Bamboo shoots with its high nutritive value and bioactive compounds have all potentials for being used for the development of modern functional foods and nutraceuticals. With increasing health consciousness amongst people and rising demand of functional foods, India and other South-East Asian countries have great opportunities to exploit its vast and rich genetic resource of bamboos for usage in the food industry for health benefits as well as socio-economic development of the people.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Figure S1. Nutrient detergent fibre (NDF) (a), acid detergent fibre (ADF) (b) and its component lignin (c), hemicellulose (d) and cellulose (e) content in various bamboo species. Values presented in the bars are means ± standard error across three replicates (n = 3).