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Bamboo shoot for food and nutritional security

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Abstract

Although appreciable advancements have been made in food processing and preservation technology; world is still struggling to provide food, health and nutrition security to large part of the population. Simultaneously, agriculture is also facing countless challenges, such as scarcity of water, decline in the size of land and adverse impact of climate change. Presently, global food security is mainly dependent on wheat, rice and maize. Meanwhile, there are hundreds of lesser known species also called underutilized species including bamboo with known economic value can play a key role in promoting food security and health. Bamboo is a fast-growing plant and can grow on degraded and marginal lands. Bamboo shoot, being nutritionally extremely rich has proved good potential for food and nutritional security and health for local communities. Freshly harvested bamboo shoot is a good source of proteins, fiber, minerals, vitamins and amino acids. Several value-added products have been prepared using fresh or fermented shoots of different bamboo species and these products occupy a significant position in the 21st century.

Keywords: Bamboo shoot, underutilized plants, nutrients, bioactive compounds, food security

Introduction

Lack of access to nutritious and balanced diet remains a major restraint to the health and well-being of people living in rural areas^[1]. Even though considerable progress have been made in food processing and preservation technology; hunger, starvation, poor health and malnutrition are still the world's greatest challenges. Currently, the Food and Agricultural Organization of the United Nation (FAO) estimates that approximately 800 million people still suffer from food and nutrition insecurity^[2]. Malnutrition and poor health are closely related since malnutrition can be a contributing cause for several chronic diseases including cancer, cardiovascular diseases and diabetes^[3,4]. According to the Food and Agricultural Organization of the United Nation (FAO), the global food production needs to be increased by 60% by 2050 to meet increasing world demands. However, agricultural land cannot be expanded due to water scarcity. Moreover, the use of fertilizers and pesticides to increase the food production will have detrimental impacts on the flora and fauna of the earth^[5].

Though wheat, rice and maize supply more than 60% of the human energy intake, these crops has led to over exploitation of ground water and other environmental problems. The circumstances instigated scientific interest in identifying alternative food resources, which can be grown on underutilized lands and tolerant to stress environmental conditions. Consequently numerous neglected and underutilized plant species offer the potential to diversity in the human diet. Most of these neglected plants have comparative advantages in marginal levels, where they have been marginally selected to withstand stress conditions and can therefore contribute to low input sustainable production systems^[6]. Bamboo is one such neglected plant which has great potential to combat malnutrition and improve health due to its nutritious and health enhancing properties^[7,8]. It is a fast-growing plant and can grow on degraded and marginal lands or in combination with other crops in agro forestry systems; thus there will be no competition for land^[9]. The Food and Agriculture Organization (FAO) recently recommended the adoption of agroforestry practices for food security in all sub-Saharan African countries (SSA) and need of SSA country government to incorporate agroforestry into their national agricultural policies. Bamboo is one such agroforestry crop that can play a significant role in eradication of hunger and malnourishment^[10]. Bamboo crop are generally ready in 5-12 years and can be harvested without removing the clump every year for the next life cycle of 30-50 years. Additionally, bamboo is grown organically without using fertilizers or pesticides and with little water, just rainwater^[11].

Bamboo shoots

The edible part of a bamboo plant is the tender shoot that has just emerged from the ground (Figure 1B, C).

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It is the young bamboo plant that emerges during the monsoon and grows into a tall bamboo plant (Figure 1A) within three to four months. For edible purpose, shoot is usually harvested after attaining 20–30 cm height. The freshly harvested shoots of many bamboo species are consumed as vegetables, salads, pickles, and in preparation of different types of curries and dishes in many Asian countries especially

in India, China and Japan [12]. Approximately 2 million tons of bamboo shoots are consumed annually [13]. Fresh juvenile bamboo shoots are delicious, crispy and healthy, with high nutritional, bioactive and antioxidant content [14]. Its use in food and medicine goes far back in history and in the present time also the importance of bamboo shoots as food has not gone down.



Fig 1: A. *Dendrocalamus hamiltonii* B. Emerging shoot C. Peeled and cut shoot

Worldwide bamboo shoots have become a multibillion dollar business. China is the biggest supplier of bamboo shoots to the world market, and earns US\$130 million annually from exports of edible bamboo shoots [15]. Approximately 200 species of bamboo provide edible and palatable bamboo shoots, though *Phyllostachys edulis* is the most preferred bamboo species for shoots production in the international market [16]. Countries like China, Taiwan and Thailand are the main suppliers of the young juvenile shoots in the international market. Many bamboo based food supplements and drugs are being produced and marketed worldwide. India, despite being the second highest repository of bamboo and highest in bamboo acreage, does not have any contribution in the global bamboo shoot market. Rather, India imports bamboo shoots from Thailand, Bhutan and China for its domestic consumption. Day by day bamboo shoot is gaining popularity worldwide as healthy and nutritious food as it is low in fat and calories and rich in edible fiber and mineral elements mainly manganese, potassium, zinc, calcium, copper, chromium, iron, phosphorus and selenium [17]. Major nutrients present in bamboo shoots are carbohydrates, proteins, minerals, vitamins and amino acids.

Nutrients in bamboo shoots

Many studies have been conducted on bamboo shoots from the perspective of food; in terms of nutritional quality and compositions, post harvest processing and storage [18]. Freshly harvested bamboo shoot contains water (91%), proteins (3.5%), fiber (1.5%), minerals, vitamins and amino acids [7, 19] [Table 1]. Eight kinds of amino acids that are not synthesized in human body can be obtained from bamboo shoots [20, 21]. Total amino acid content of shoots of different bamboo species ranges from 3.01g (*Dendrocalamus brandisii*) to 3.98 g/100g, fresh weight (*Bambusa bambos*). Bamboo shoots contain arginine and tyrosine as the major amino acids that otherwise is a minor component in common fruits and vegetables [22, 23]. Bamboo shoots are also a rich source of

proteins, which are very important for the growth and development, and also required for the maintenance of all biological functions of the body. Protein content in shoots of different bamboo species ranges from 19.2 to 25.8 g/100g, dry weight [24]. According to Nirmala *et al.* [17] protein content in the shoots of different bamboo species ranges from 2.31 to 3.72 g/100 g, fresh weight. Freshly harvested bamboo shoots are also a good source of carbohydrates but with age, carbohydrate content decreases. Nirmala *et al.* [17] reported reduction of carbohydrates with increase in age, as 10-day-old shoot (2.30 g/100 g, fresh weight) had lesser carbohydrate content as compared to freshly harvested shoots (5.42 g/100 g, fresh weight). The shoots are known as a heart protective vegetable because of its high content of potassium and low content of fat. Potassium content in bamboo shoots ranges from 232 to 576 mg/100g, fresh weight [7]. Regarding fat content, Bhatt *et al.* [25] reported maximum fat content (1.00 g/100g, fresh weight) in shoots of *B. nutans* while the minimum (0.10 g/100g, fresh weight) in shoots of *D. strictus*. Other important minerals present in bamboo shoots are phosphorus, sodium, calcium, magnesium, iron and selenium. Selenium acts as a co-factor for an enzyme, glutathione peroxidase and plays an important role in growth and development.

Bamboo shoots are also a good multivitamin food that can act as a foundation of good health [24]. The vitamin C content, as determined by Nirmala *et al.* [7] in the fresh shoots of various bamboo species ranges from 1.00 mg to 4.80 mg/100 g, fresh weight. Bhatt *et al.* [25] also reported vitamin C content for a number of bamboo species ranging from 3.0% to 12.9%, with highest in *Dendrocalamus hamiltonii* and lowest in *D. sikkimensis*. Rawat *et al.* [26] evaluated the vitamin C content of shoots of three bamboo species namely, *D. giganteus*, *D. latiflorus*, and *D. sikkimensis* and found that *D. sikkimensis* (2.43 mg/100g, fresh weight) has higher vitamin C content followed by *D. latiflorus* (2.38 mg/100g, fresh weight), and *D. giganteus* (2.21 mg/100, fresh weight). Similarly, vitamin E content of shoots of various bamboo species ranges from

0.42% to 0.91% [27]. Hu *et al.* [28] conducted a study on the changes in nutrient composition of the shoots at different ages and concluded that the shoots become inedible with age. The fiber content in the shoots increases with age but nutrients like proteins, amino acids, fat, and carbohydrates, decrease with age of the shoots. A study conducted by Nirmala *et al.* [17] to determine the nutrient changes with age in juvenile shoots of five bamboo species *viz.* *Bambusa bambos*, *B. tulda*, *Dendrocalamus asper*, *D. giganteus*, and *D. hamiltonii* and found that nutrient components of the shoots depleted in all the five species with ageing but the dietary fiber and moisture content increased. Being a rich source of nutrients, antioxidants and bioactive compounds, bamboo shoots could help in solving nutritional deficiency through food fortification.

Bioactive compounds in bamboo shoots

The fresh juvenile shoots have been used from ancient times as food and medicine and have now gained recognition for its functional merits as a food antioxidant, cosmetic ingredient and as a nutraceutical component for preventing diseases. Modern scientific research has supported most of the medicinal properties of bamboo such as anti-oxidant, anti-diabetic, anti-microbial, anti-tumour, prevention of cardiovascular and neurological disorders etc. All these medicinal benefits have been attributed to the presence of numerous pharmaceutically active compounds in bamboo shoot which makes shoot an ideal bio-resource for the development of novel functional foods and nutraceuticals.

Global nutraceutical industry is expected to reach \$ 285 billion by 2021. India boasts a mammoth 15.69 million hectares of natural bamboo spread which is highest in the world.

A large number of studies have demonstrated that bamboo shoots are a good source of dietary fiber, phenols and phytosterols [29] (Table 2). The dietary fiber possesses number of health benefits as they control blood pressure, hypertension, and obesity and also protect the body from coronary heart diseases and potential carcinogens. Regular consumption of bamboo shoots improves the lipid profile and bowel movement [30]. Besides dietary fiber, shoots have high content of phenolic compounds and phytosterols which possess various bioactivities such as anti-inflammatory, antioxidants, serum cholesterol lowering, anti-ulcer, and anti-cancer [30, 31]. Park and Jhon [32] identified eight phenolic compounds, ferulic acid, p-coumaric acid, caffeic acid, protocatechuic acid, p-hydroxybenzoic acid, catechin, syringic acid and chlorogenic acid in bamboo shoots using high-performance liquid chromatography. The phenolic content of shoots of different bamboo species ranges from 191.37 mg/100g to 630.0 mg/100g, fresh weight. Regarding phytosterols, β -sitosterol, campesterol, and stigmasterol are the major sterols identified in bamboo shoots [33]. Ingudam and Sarangtham [34] analyzed twelve edible bamboo species for their phytosterol content and found that phytosterol level varied in bamboo shoot sample of different species ranging from 293.8 to 40.5 mg/100g, dry weight.

Table 1: Nutrient content (macronutrients g/100g, fresh weight; vitamin C & E mg/100g, fresh weight) in shoots of different bamboo species

Bamboo species	Proteins	Amino acids	Carbohydrate	Fat	Starch	Vitamin C	Vitamin E	Reference
<i>Bambusa bambos</i>	3.57	3.98	5.10	0.50	0.25	1.90	0.61	[7]
<i>B. balcooa</i>	2.74	-	3.90	-	-	-	-	[35]
<i>B. kingiana</i>	3.57	3.70	5.50	0.35	0.34	2.10	0.50	[7]
	3.72	-	5.50	0.41	0.34	-	-	[17]
<i>B. nutans</i>	2.84	3.89	5.40	0.40	0.21	1.19	0.47	[7]
	4.34	5.26	1.04	-	0.71	2.79	0.12	[36]
	3.52	-	2.76	0.31	1.37	-	-	[37]
<i>B. pallida</i>	2.31	-	3.83	-	-	-	-	[35]
<i>B. polymorpha</i>	3.64	3.42	5.44	0.46	0.38	2.60	0.49	[7]
	2.10	-	4.86	-	-	-	-	[35]
<i>B. tulda</i>	3.69	3.65	6.92	0.48	0.59	1.42	0.61	[7]
	2.88	-	4.43	0.40	0.48	-	-	[37]
	3.69	-	6.92	0.48	-	-	-	[17]
<i>B. vulgaris</i>	3.64	3.57	6.51	0.50	0.27	4.80	0.52	[7]
	2.33	-	2.43	0.14	-	-	-	[38]
<i>Dendrocalamus asper</i>	3.59	3.12	4.90	0.40	0.36	3.20	0.91	[7]
<i>D. brandisii</i>	2.31	3.01	4.90	0.24	0.49	1.59	0.42	
<i>D. giganteus</i>	3.11	3.86	5.10	0.39	0.51	3.28	0.69	[37]
	2.63	-	0.56	4.66	-	-	-	
<i>D. hamiltonii</i>	3.72	3.18	5.50	0.41	0.47	2.45	0.71	[7]
	2.83	3.24	4.33	-	0.49	-	-	[39]
	3.50	-	5.30	0.29	-	0.80	-	[22]
	2.93	-	0.40	3.44	0.37	-	-	[37]
	2.60	-	4.00	-	-	-	-	[35]
<i>D. hookerii</i>	3.40	-	4.50	1.00	-	-	-	[35]
<i>D. latiflorus</i>	24.50	-	28.50	3.80	-	-	-	[40]
<i>D. longispachus</i>	2.60	-	4.70	0.60	-	-	-	[35]
<i>D. membranaceus</i>	3.38	3.46	5.40	0.43	0.23	1.58	0.65	[7]
<i>D. sikkimensis</i>	3.10	-	4.70	-	-	-	-	[35]
<i>D. strictus</i>	2.60	3.07	6.17	0.33	0.31	2.43	0.58	[7]
<i>Gigantochloa albociliata</i>	3.05	3.52	4.59	0.51	0.31	1.00	0.60	
<i>G. rostrata</i>	3.56	3.17	4.32	0.56	0.22	3.20	0.49	[35]
<i>Melocana baccifera</i>	2.40	-	4.80	-	-	-	-	[41]
<i>Phyllostachys pubescens</i>	1.59	-	22.50	1.77	-	-	-	[35]
<i>Teinostachyum weightii</i>	3.60	-	4.90	-	-	-	-	[38]
<i>Yushania alpine</i>	33.40	-	23.60	2.00	-	-	-	[38]
<i>Y. alpine</i>	33.00	-	17.30	2.00	-	-	-	

Table 2: Bioactive compounds in bamboo shoots (Dietary fibre: g/100g fresh weight, Phenols: mg/100g fresh weight, Phytosterols: mg/100g dry weight)

Bamboo species	Phenols	Phytosterols	Dietary fibre	Reference
<i>Bambusa bambos</i>	-	-	3.54	[7]
<i>B. balcooa</i>	-	124	-	[42]
	382	-	-	[43]
	-	180*	-	[34]
<i>B. kingiana</i>	-	-	4.49	[7]
	-	127*	-	[34]
<i>B. nutans</i>	703	-	2.28	[7, 17]
	465	152	-	[42]
	490	-	-	[44]
<i>B. polymorpha</i>	-	164	-	-
	-	-	3.81	[7, 17]
<i>B. tulda</i>	444	-	3.97	-
	473	167*	-	[34, 42]
	-	95	-	[34]
<i>B. vulgaris</i>	-	-	4.24	-
<i>Dendrocalamus asper</i>	580	-	3.54	[7, 17]
<i>D. brandisii</i>	-	-	4.03	-
<i>D. hamiltonii</i>	586	198	-	[44]
	530	-	-	[43]
	-	218	-	[34]
<i>D. giganteus</i>	336	-	2.65	[7, 43]
	612	136	-	[44]
	-	158	-	[42]
	-	173	-	[34]
	-	-	3.90	[7]
	-	-	1.50	[19]
<i>D. membranaceus</i>	596	-	2.91	[7, 42]
	-	162	-	[44]
	-	161	-	[43]
<i>D. strictus</i>	630	-	2.26	[7, 17]
	-	187	-	[34]
<i>Gigantochloa albociliata</i>	-	-	4.15	[7]
<i>G. rostrata</i>	-	-	4.20	-

The role of bamboo shoots in food fortification

Bamboo shoots, with their high nutritive and therapeutic value hold a great promise for utilization as a health food [7]. Shoots of various bamboo species have been used for making delicious novel food products like chutney, pulao, halwa, curry, and bhaji etc (Table 3). These food products have also been standardized by Engineering Resource Group, Bangalore [45]. Number of bamboo shoot-based products is commercially available in the markets of different countries including China, Japan, Thailand, and Malaysia. These products include canned bamboo shoots, fermented bamboo shoots, bamboo shoot pickle, bamboo shoot powder, and bamboo shoot juice [22]. Sood *et al.* [19] prepared some edible products such as

preserve, candy, chutney, nuggets, cracker and chukh using juvenile shoots of *Dendrocalamus hamiltonii*. Results showed that bamboo shoots improved their nutritional and organoleptic qualities. Other products like pork nuggets, chicken nuggets, pork pickle, chips, and biscuits have been prepared, using fresh or fermented shoots of different bamboo species (*Bambusa auriculata*, *B. bambos*, *B. tulda*, *B. polymorpha*, *B. balcooa*, *B. vulgaris*, *Dendrocalamus asper*, *D. strictus*). These products when analyzed for their nutritional and organoleptic qualities, it has been found that, products containing fresh or fermented bamboo shoots revealed significantly higher mean sensory scores in terms of flavor, texture, juiciness and overall acceptability.

Table 3: Bamboo shoot fortified products

Fortified product	Bamboo Species	Reference
Biscuits	<i>D. hamiltonii</i>	[46]
Biscuits	<i>B. balcooa</i>	[47]
Biscuits	<i>D. hamiltonii</i>	[48]
Battered and breaded fish balls	-	[49]
Chicken nuggets	<i>B. auriculata</i>	[50]
Candy, Chutney, Chukh, Cracker, Nugget	<i>D. hamiltonii</i>	[19]
Crackers, Nugget, Pickle	<i>B. bambos</i> , <i>B. tulda</i> , <i>D. asper</i> , <i>D. strictus</i>	[51]
Chips	<i>B. vulgaris</i>	[52]
Candies	-	[53]
Cookies	-	[54]
Cookies	<i>D. asper</i>	[55]
Milk pudding	<i>D. latiflorus</i>	[56]
Pork Nuggets	<i>B. polymorpha</i>	[57]
Pork Nuggets	<i>B. polymorpha</i>	[58]
Pork Pickles	-	[59]

D: *Dendrocalamus*; B: *Bambusa*; (-): Not mentioned

Market potential and Future prospects

Bamboo shoots are low in fat and high in nutrients, bioactive compounds and antioxidants and are gaining popularity worldwide for utilization as healthy and nutritious food [7, 19]. The international market for bamboo shoots has grown to over \$150 million per year from China alone. Approximately half goes to Japan [60]. India is the second largest bamboo producing country in the world next to China with annual production of 32.3 million tonnes [61]. Bhatt *et al.* [25] worked out the sales of fermented, roasted and boiled bamboo shoots in the markets of Arunachal Pradesh, Manipur, Meghalaya, Nagaland, Sikkim and North-Eastern Himalayan region with the results being based on the survey of 118 markets covering 1200 primary and secondary vendors from 51 districts of North-Eastern Himalayan region. The consumption of fermented, roasted and boiled shoots was estimated to be approximately 680 tonnes; the highest occurs in Arunachal Pradesh (481 tonnes/year) and the lowest in Nagaland (19.5 tonnes/year). The bamboo shoots are found to be consumed in the form of fermented-slice, crushed-fermented moist, crushed-fermented dry, fermented whole shoot, roasted whole shoot and boiled whole shoots in different states of the region [21]. Cost-return analysis for sales of these bamboo products revealed a net income of 23 million rupees per annum from the entire region with highest (17.5 million rupees/year) in Arunachal Pradesh and the lowest in Sikkim (0.47 million rupees/year) [25]. The size of market for bamboo shoot products in India were estimated by National Mission on Bamboo Trade and Technology Development in 2003 and reported to be Rs. 4.8 crore in 2001 with expected rise to Rs.300 crore in the year 2015 [62]. The annual consumption of bamboo shoots in the north eastern states of India has been reported to be 1979 tonnes, 2188 tonnes, 442 tonnes, 433 tonnes, 442 tonnes and 201 tonnes in Arunachal Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura respectively. It is estimated by the Planning Commission that the Indian bamboo shoot industry has the potential to grow at the rate of 255 per annum and capture a market worth rupees 300 crores. Recent studies have also elucidated the potential of bamboo based charcoal composites in water purification and treatment of pharmaceutical wastes as bamboo based charcoal is associated with high surface area and absorption properties [63].

Conclusion

The biggest global challenges are food insecurity, hunger and malnutrition that need immediate attention of the food scientist and researchers. In addition to staple crops, there are innumerable underutilized species on the earth including bamboo with known economic value can play a key role in promoting food security and health. Bamboo shoot is extremely rich in nutrients and bioactive compounds and has the potential to solve current problems. It is an ideal material which can be used for the production of novel and healthy food items through food fortification. The current research on bamboo is leading to emergence of new avenues to utilize different parts of bamboo especially bamboo shoots for the production of novel food products and nutraceuticals.

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Conflict of interest

The authors declare that there are no conflicts of interest.

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