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REVIEW

Bamboo shoot: a potential source of food security

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Abstract Energy, climate change, food security, and health care are the major challenges humanity is facing the world over. Bamboo grass, which can grow successfully on wasteland with minimal agronomical inputs, would help in meeting these challenges to a significant extent. Generally, bamboos, a group of large woody grasses belonging to the family *Poaceae* and subfamily *Bambusoideae* are much known for their contribution mainly to the housing sector in view of certain unique characteristics. Although the bamboo shoot used in tribal diet is a very old phenomenon, yet the food potential of the bamboo shoot per se remains subsided and unexplored. Literature on the food potential of bamboo shoots is scattered and has been realized in a reductionistic manner. Few studies reveal its richness in nutritive components like protein and fiber content and thus the bamboo shoot could be helpful in mitigating the problem of malnutrition. This paper therefore tries to reflect light on the bamboo shoot as a food resource with a holistic perspective. Exotic food products and traditional dishes of bamboo shoots being eaten at different locations have been compiled and discussed. The toxic content in different bamboo shoot species studied by various investigators is presented in this paper too. The nutritional values of different species of bamboo shoots and the effect of processing methods on its nutritive quality have also been looked into. The feasibility of integrating raw/processed bamboo shoot in the modern diet and lifestyle for enhancing food-nutritional security is also explored.

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Introduction

The modern agriculture system now is at the crossroads, especially due to stagnant productivity, environmental problems such as declining soil fertility and ground water pollution as well as very high input cost. Exorbitant increase in food prices and non-availability of quality food commodity has shaken the foundation of the world community. This sort of 'hungry' situation leads to several problems including a sense of insecurity among the people [1, 2]. A shift in paradigm of food production and management has been recommended to handle the socioeconomic dynamics [3]. Non-timber forest products (NTFPs) are products of biological origin (other than wood) derived from forests. NTFPs have long been an important component of the livelihood and food security strategies of forest-dwelling people including tribal. Several million households worldwide depend heavily on NTFP for sustenance as well as for meeting family nutrition. According to FAO estimates, approximately 80% of the population of the developing world use NTFP for health care and nutrition. In addition to providing subsistence income, commercial value of NTFP has been increasing. Over 150 NTFPs are considered as significant commodities in international trade. Important products traded from the tropics include rattan, Brazil nuts, gum arabic, lac, bamboo shoots, and various spices and herbal products [4].

Bamboos are mainly found in the mixed deciduous and tropical evergreen forests and partly found in the dry Dipterocarp forest. More than 1,250 species belonging to 75 genera are distributed worldwide of which 125 species

are spread in India over an area of 9.57 million hectares. India has rich bamboo resources after China [5]. The northeastern states are endowed with more than 50% of the Indian bamboo genetic resources. Besides being much useful for human life, it prevents soil erosion, conserves soil moisture, and is of immense significance in environmental protection. Despite its wide usage in the structural and building materials, it forms an essential component in cottage and rural industry [6]. From ancient times, the bamboo shoot and its products as food have been consumed by the tribal community world over. The present paper explores the food potential of the bamboo shoot harvested from various edible species around the globe, and future scope of value addition by scientific and technological inputs for food security.

Bamboo shoot: a food resource

A bamboo shoot is the young bamboo plant, which if not harvested, will grow into a tall bamboo plant within 3–4 months. Bamboo shoots usually emerge after the rainy season and are harvested after attaining 20–30 cm height. Exposure to light causes bitterness as cyanogenic glycosides are formed in the shoot. In Japan, bamboo shoots are forced to grow under mulch heated with electric cables placed 6–8 cm below the soil. Mulched bamboo shoots can be harvested earlier than those growing in the natural environmental conditions [7]. It is the just emerging tender shoots (not the aerial shoots: culms and branches) that are eaten [8]. Young shoots of both running and clump forming bamboos are used for edible purposes.

Bamboo shoots are crisp and tender comparable to asparagus and eaten fresh, but can be canned or frozen. Commercial processing of bamboo shoots involves washing followed by peeling of the skin, shredding, slicing, and cutting into cones. Next, they are boiled for about 10 min to remove bitterness. This is then followed by storing in brine solution with 5% salt and 1% citric acid. Finally, the processed shoots are vacuum packaged in 100 g packets containing 25 ml brine solution [9]. However, the tribal people of the northeast have evolved different indigenous techniques of processing: slicing, shredding, fermenting, pickling, and drying [9, 10].

Bamboo is not merely the poor man's timber but is also the rich man's delicacy. Bamboo shoots exhibit a great potential as a food resource. For centuries, young edible bamboo shoots have remained one of the highly palatable dishes in delicacies. As early as in 1951, production and use of fine quality edible bamboo shoots in eastern China and Japan was reported [11]. China and Taiwan are among the leading countries that export edible bamboo shoots [12]. Fresh, fermented and roasted tender bamboo shoots are considered culinary treats. They are consumed as vegetables, pickles, salads, and in various other forms in different countries [13, 14]. Tender shoots of some species are also preserved after fermenting and drying [15]. Bamboo shoots are a popular item in Asian stir-fry and as a pickled condiment [16].

Bamboo shoot flavor, recipes and export potential

Fresh shoots have a crisp and sweet flavor with a limited shelf life [9]. Freshly harvested shoots are bitter and acrid in taste. A characteristic taste of bamboo shoot, called *egomi* or *egumi* in Japan, which irritates the root of the tongue, had been investigated [17]. Homogentisic acid was found to be responsible for the disagreeable pungent taste in shoots [15]. It was also found that bamboo shoots grown in dark brown soil have more homogentisic acid and stronger egumi taste than those grown in light brown soil and the top part contained more egumi taste and homogentisic acid than the base [18].

Bamboo shoots are a popular food in Asia, and the nutritional value is comparable to those of many commercial vegetables [19]. There are around 11 popular intercontinental dishes prepared from bamboo shoots in Indian restaurants [20]. Bamboo shoots have been integrated in the north and south Indian cuisine. Recipes like bamboo shoot *halwa, chutney, pulao, curry, bhaji*, etc. have been standardized by Engineering Resource Group, Bangalore [21]. Bamboo shoots form a common ingredient of Chinese dishes [22]. Products commercially available in China, Japan, Thailand, and Malaysia include canned bamboo shoots, fermented shoots, bamboo pickle, bamboo shoot powder, bamboo shoot juice, and bamboo beer (prepared from bamboo culms).

The ideal edible bamboo shoot for processing should be white, solid, and tender and should lack bitterness and acridness. The shoots are used for making curry or chutney either alone or in combination with potatoes, tomatoes, and peas, etc. [23]. *Tusa* (young bamboo shoots) and bamboo *tama* (fermented young shoot) are important delicacies for hill people in the western hills of Nepal [24]. They are also consumed in Ethiopia by the rural people living near the bamboo forests, albeit less popular. Boiled rhizomes are also eaten in these areas. Bamboo shoot could also probably be used to supplement food requirements in Ethiopia [25].

Export of boiled and fresh bamboo shoots takes place in various parts of the world from the point where they are processed. Dried bamboo shoots are not exported due to an imposed ban by the local authorities of Vietnam because of concerns that the resources will be depleted [26]. The total potential of bamboo worldwide is estimated at $10 billion.

In the international market, China earns US$130 million every year from exports of edible bamboo shoot, with imports of US at around 44,000 tonnes accounting for 14.5% of the total world imports and import of Australia is at 8,000 tonnes per annum. Every year US imports 30,000 tonnes of canned bamboo shoots from Taiwan, Thailand, and China. Taiwan consumes 80,000 tonnes of bamboo shoots annually constituting a value of US$50 million. In Japan, the annual per capita consumption of bamboo is now 3 kg per person presently, compared to 1.2 kg per person in the 1950s [27].

Fermented foods are not only attractive and palatable in terms of flavor, aroma, texture, and appearance but are also rich in nutrients and good for digestion. In India, the fermentation of bamboo shoots has extensively been carried out in the states of Manipur, Meghalaya, Sikkim, Mizoram, etc. since ancient times [28, 29]. Seventy volatile compounds were detected from fermented Bamboo shoots (Phyllostachys pubescens) prepared in a traditional Taiwanese manner, out of which 29 possessed aromatic activity, and the most odor active included p-cresol (barn-like), 2-heptanol (mushroom), acetic acid (vinegar), and 1-octen-3-ol (mushroom) [30].

Food safety aspect of bamboo shoot

Several studies have reported that bamboo shoots contain cynogenic glycoside, which can prove hazardous to health if not processed properly and if consumed in excess. Taxiphyllin (4-hydroxy-(R)-mandelonitrile-b-D-glucopyranoside), a cynogenic glycoside [31] has been found to be the potential toxic component present in the different species of bamboo shoots like *Dendrocalamus latiflorus, D. giganteus, D. hamiltonii, Bambusa vulgaris* and *B. guadua* [32–35]. The cyanide (HCN) content varies in different parts of a plant and also between the same parts of different portions of the same species [36]. For e.g., the top, middle and base portion of bamboo shoots differ in their cynogenic content. Table 1 describes the toxic content in different parts of various species. The enzymatic hydrolysis of taxiphyllin by β-glucosidase yields glucose and 4-hydroxy (R) mandelonitrile, which are further hydrolyzed to HCN and benzaldehyde [37]. The acute lethal dose of HCN for humans is 0.5–3.5 mg/kg body weight, and for animals, it is 0.66–15 mg/kg body weight [36]. However, FAO/WHO Codex Alimentarius has defined a safe limit for human consumption, which is 10 mg HCN equivalent per kg dry weight [38]. However, when the dose is relatively small, humans are able to detoxify HCN by the enzyme Rhodanese forming thiocyanate, which is excreted in the urine. Chronic cyanide poisoning sets in due to lack of nutrients like riboflavin, protein, vitamin B_{12}, sodium, and methionine. The detoxification requires sulphur amino acids like cysteine and methionine in the diet [39]. Processing techniques like soaking, cutting, boiling, canning, etc., reduce the cyanide content to a great extent [40, 41]. Therefore, proper processing of raw bamboo shoot (i.e., boiling, fermentation, drying, etc.) should be carried out and tested for toxic content before marketing of various products.

Table 1 Cyanide content in various bamboo shoot species

Bamboo species	Portion	Cyanide content (ppm)	References
D. giganteus Munro and D. hamiltonii Nees et Arnott	Whole	900–1,000	[34]
Dendrocalamus giganteus	Whole	894	[40]
Dendrocalamus hamiltonii	Tip	2,420	[27]
	Middle	860	
	Base	150	
Bambusa pallida	Tip	270	
	Middle	170	
	Base	130	
B. tulda	Tip	170	
	Middle	830	
	Base	280	
B. balcooa	Tip	2,150	
	Middle	1,380	
	Base	620	
Melocanna bambusoides	Tip	1,810	
	Middle	680	
	Base	350	
Species not mentioned	Apical part	1,000	[69]
Species not mentioned	Tip	8,000	[70]
Species not mentioned	Whole	551	[71]
Species not mentioned	Tip	1,600	[72]
	Base	110	

Nutritive value of bamboo shoot: a broad profile

Although the different parts of the bamboo are used as a food resource by humans and animals, a systematic conclusive study on its nutritional significance is not available. Bamboo shoots contain several nutritional components like protein, carbohydrates, fat, vitamins, minerals, enzymes, coenzymes, reducing and non-reducing sugars, lactic acid, and citric acid (fermented products), etc. The bamboo shoot is rich in fiber and low in fat; 100 g of edible portion of bamboo shoots contains 2.6 g of protein and 0.3 g of fat [7]. Some Indian studies have reported the protein value to be high in the range 21.1–25.8% on a dry weight basis [13,

42]. An increase in the protein value (29.6%) has been found in the processed and dried bamboo shoots [43]. It contains tyrosine as the major amino acid which otherwise is a minor component in common fruits and vegetables [44]. It also contains selenium, an important antioxidant and lysine "one limiting amino acid" which lacks cereals and is an important amino acid for growth and development. The main fatty acids present in bamboo shoots are palmitic, linoleic, and linolenic acids [45]. Fresh bamboo shoots have also been found to be rich in potassium (533 mg/100 g), which helps prevent heart diseases and blockage of blood vessels [46].

Young [47] was the first to report the nutrients present in raw bamboo shoot (species not mentioned) in terms of crude protein, crude fat, carbohydrate, and ash. Gradually interest in this non-forest product was revived after about three decades. Subsequently, detailed analysis of nutrients in different species was performed by various scientists [12, 13, 15, 43, 47–53]. Various investigators have compiled the nutritive value (macronutrients) of 100 g of edible bamboo shoots (Table 2).

The significance of macronutrients and micronutrients in diet for human health and the possibility of substituting these elements by integrating bamboo shoot in food matrix are presented here.

Macronutrients

Protein

Bamboo shoots are rich in protein and amino acids essential for the human body. Investigation by Kumbhare and Bhargava [13] on *B. nutans, B. vulgaris, D. strictus* and *D. asper* species of shoots reported values, which ranged from 19.2 to 25.8% (dry weight basis) and were found in accordance with the earlier reports [13]. The apical and the basal portions of *D. giganteus* were found to have higher values, i.e., 46.1 and 40.4%, respectively [54]. Crude protein estimated by CHN Analyser at IIT, Delhi, for *D. strictus, B. tulda, B. vulgaris* and *B. balcoa* was found to be 21.51, 18.74, 20.60 and 25.84, respectively [42]. According to a recent report, the protein content in the juvenile shoots ranged from 2.31 to 3.72 g/100 g fresh weight in 14 bamboo species, the highest being in *D. hamiltonii* followed by *B. bambos* [55]. The wide variation in the protein content of bamboo shoots may be attributed to differences in species, growing site, climatic factors, and method of analysis.

The crude protein content decreased after boiling the shoots at increasing temperature. The content decreased from 17.3 to 11.6% on dry weight basis, highest being in *B. nutans*. Cooking diminishes the biological value of proteins by destroying the essential amino acids. Such a decrease in crude protein content of 1.7% in peeled potato as compared to the uncooked potato (2.1%) has been mentioned in a FAO report [56]. The content was also found to decrease in the 10-day-old shoots (2.17–2.60%) when compared with the freshly harvested juvenile shoots (3.10–3.71%) in four different species [50]. This detailed study by Nirmala et al. [51] revealed that canned shoots have the lowest protein content (1.93%) followed by fermented (2.57%), 10-day-old (2.6%), and juvenile shoots (3.11%) in the *D. giganteus* species [51].

Carbohydrates

The carbohydrate content ranges from 2.0 to 9.94% in the raw form of bamboo shoots as investigated by different researchers. The carbohydrate content as reported by Kumbhare and Bhargava [13] was 3.3, 3.4, 2.6 and 2.9% in *B. nutans, B. vulgaris, D. strictus and D. asper*, respectively. The content was found to increase after boiling, ranging from 3.1 to 5.1%, which may be due to the fibrous nature of bamboo. During processing, the polysaccharides may be hydrolyzed into simple sugars resulting in the formation of monosaccharides. The oligosaccharides such as stachyose and raffinose, which cause flatulence, can be converted to monosaccharides and thus the cooking of bamboo shoots could be beneficial [13]. Similarly, the carbohydrate content ranged from 4.09 to 6.91% in 14 species of freshly emerged juvenile bamboo shoots; there was an increase in the content after boiling and also after fermentation and canning up to 72% [51, 55].

Fats

Bamboo shoots are known for their low fat content and contain important essential fatty acids. The fat content ranged from 0.3 to 3.97% in the fresh shoots, highest being in *B. tulda*. Canned shoots were reported to contain the lowest content of crude fat, i.e., 0.25% as compared to the raw shoots of different species. As shown by Nirmala et al. [50], fat content increased upon keeping the shoots for 10 days by almost threefold in three species (*B. bamboos, B. tulda and D. asper*), and in one species, *D. giganteus*, the increase was exceptionally high by sixfold. The fat content in the juvenile shoots ranged from 2.64 to 3.97%, but for the 10-day-old shoots, the content ranged from 8.2 to 13.84% [50, 51, 55].

Variation in the distribution of lipids between different sections of the shoot has been reported. Total lipids (TL) ranged from 800 (top) to 380 mg (base) per 100 g fresh weight and the ratio of nonpolar lipids (NPL):glycolipids (GL):phospholipids (PL) was about 17:27:56. The main fatty acids were palmitic, linoleic, and linolenic acids, but composition was remarkably different among different sections [45].

Table 2 Nutritive value of bamboo shoot harvested from different bamboo species

Name of the species	Part of the plant	Processing condition	Calories (Kcal)	Moisture (%)	Crude protein (%)	Crude Fat (%)	Carbohydrate (%)	Ash (%)	Crude fiber (%)	References
Species not mentioned	Shoot	Raw	14	NS	1.80	0.30	2.00	NS	1.29	[56]
	Shoot	Raw	NS	88.8	3.90	0.50	5.70	1.10	NS	[73]
	Shoot	Raw	NS	NS	2.60	0.30	4.50	0.90	NS	[47]
	Shoot	Raw	43	88.8	3.90	0.50	5.70	1.10	NS	[52]
	Shoot	Raw	27	91.0	2.60	0.30	5.20	NS	NS	[7]
	Shoot	Raw	NS	87.10	3.90	NS	7.50	1.40	NS	[53]
	Shoots	Processed and dried	294	11.60	29.6	0.40	43.0	8.50	6.90	[43]
B. bamboos	Shoot	Raw	NS	88.80	3.90	0.50	5.70	NS	NS	[48]
	Shoot	Raw	NS	89.83	3.57	3.53	5.42	1.38	3.53	[50]
	Shoot	10 days old	NS	90.80	2.32	9.64	2.30	1.22	9.64	[50]
B. balcoa	Shoot	Raw	15.5–15.64	84–86.3	3.3–3.87	0.6–1.0	5.2–5.23	3.1	26.4	[12, 49]
	Shoot	Raw	NS	91.65	2.74	0.817	3.90	0.99	NS	[21]
	Shoot	Raw	NS	NS	25.84	NS	NS	NS	NS	[42]
B. polymorpha	Leaves, shoot	Raw	NS	74.0	7.46	NS	8.0	NS	NS	[15]
	Shoot	Raw	NS	91.65	2.10	0.44	4.86	0.91	NS	[21]
B. nutans		Raw	15.4	94.70	3.30	1.0	4.90	2.70	28.50	[12, 49]
	Shoot	Raw	NS	NS	21.10	NS	3.30	0.90	0.76	[13]
		Boiled	NS	NS	17.30	NS	5.10	0.72	0.75	[13]
B. vulgaris	Shoot	Raw	NS	77.0	4.16	NS	5.0	NS	NS	[15]
	Shoot	Raw	NS	NS	25.70	NS	3.40	0.80	0.97	[13]
		Boiled	NS	NS	13.50	NS	5.0	0.66	0.97	[13]
		Raw	NS	NS	20.60	NS	NS	NS	NS	[42]
B. tulda	Shoot	Raw	15.90	92.80	3.40	0.9	4.70	3.0	24.60	[12, 49]
	Shoot	Raw	NS	83.60	3.69	3.97	6.92	0.85	3.97	[50]
	Shoot	10 days old	NS	89.33	2.49	10.69	2.58	0.74	10.69	[50]
			NS	NS	18.74	NS	NS	NS	NS	[42]
M. baccifera	Shoot	Raw	NS	84.0	7.36	NS	2.0	NS	NS	[15]
	Shoot	Raw	15.8	75.5–93.0	2.4–3.62	0.57–1.0	4.5–6.12	2.30	35.5	[12, 49]
Dendrocalamus strictus	Shoot	Raw	NS	NS	19.20	NS	2.60	0.90	0.98	[13]
	Shoot	Boiled	NS	NS	17.10	NS	5.0	0.82	0.96	[13]
	Shoot	Raw	NS	85.98	1.98	0.82	9.94	1.14	–	[21]
			NS	NS	21.51	NS	NS	NS	NS	[42]
D. hamiltonii	Shoot	Raw	16.40	87.0–93.6	3.7–3.9	0.5–0.9	4.8–5.7	2.80	25.4	[12, 49]
	Shoot	Raw	NS	92.51	3.72	3.90	5.50	0.86	3.90	[50]
	Shoot	10 days old	NS	92.60	2.56	8.20	2.98	0.84	8.20	[50]
	Shoot	Raw	NS	92.37	2.60	0.314	4.00	1.01	NS	[21]
D. giganteus	Shoot	Raw	16.9	92.00	2.80	0.80	4.90	2.20	27.60	[12, 49]
	Shoot	Raw	NS	90.7	3.11	2.64	5.10	0.89	2.64	[50]
	Shoot	10 days old	NS	91.8	2.60	13.84	5.02	0.74	13.84	[50]
	Shoot	Fermented	NS	88.83	2.57	0.315	1.50	0.78	–	[51]
	Shoot	Canned	NS	95.16	1.93	0.25	1.45	0.75	–	[51]
	Shoot	Raw	NS	91.19	2.59	0.502	4.78	0.89	–	[21]
D. asper	Shoot	Raw	NS	NS	25.8	NS	2.90	0.80	0.71	[13]
	Shoot	Boiled	NS	NS	11.60	NS	3.10	0.75	0.70	[13]
	Shoot	Raw	NS	89.40	3.59	3.54	4.90	0.95	3.54	[50]
	Shoot	10 days	NS	90.20	2.17	10.85	4.46	0.94	10.85	[50]

Fiber

Bamboo shoots are a good source of edible fiber, which helps in lowering the blood cholesterol. *M. baccifera* contained the highest content of crude fiber at 35.5% [49]. The study revealed higher crude fiber content ranging from 23.1 to 35.5% in different species of shoots. Duke and Atchley [57] and Kumbhare and Bhargava [13] found the lowest value of 0.71% in *D. asper* amongst all the species [13, 57]. The fiber content as determined by Kumbhare and Bhargava [13] in the raw shoots ranged from 0.71 to 0.98% and there was not much significant reduction in the fiber content after boiling [13]. The apical and basal portions of D. giganteus shoots contained 0.96 and 0.97% crude fiber on fresh weight basis [54]. The fiber content in the juvenile shoots ranged from 2.64 to 3.97%, whereas for 10-day-old shoots, the increase ranged from 8.2 to 13.84% [50]. According to a recent report, some species of bamboo have high amounts of fiber, ranging from 2.26 to 4.49 g/100 g fresh weight of shoot, maximum being in *B. kingiana* (Gamble) [55]. Nirmala et al. [50], however, pointed out that dietary fiber in shoots increased approximately three-fold after keeping for 10 days. The content also increased significantly after fermentation and canning [51]. After bamboo shoots were harvested, the fiber content increased quickly from the cut end towards the tip. In a study, it was evident that upon storage, the enhancement of the activity of the enzyme, phenylalanine ammonia lyase (PAL) was closely correlated with the increase of crude fiber and lignin [58].

Micronutrients

Vitamins

Water-soluble vitamins *Thiamine, Riboflavin and Niacin*. Not many studies have reported the vitamin content in fresh shoots, although bamboo shoots form an important delicacy in the northeastern part of the world. Yamaguchi [7] looked at the vitamin A (20 IU), B_1 (0.15 mg/100 g), B_2 (0.07 mg/100 g), B_3 (0.60 mg/100 g), and C content in shoots but other studies tried to focus only on the vitamin C content of shoots. Rajyalakshmi and Geervani [43] revealed that thiamine (0.05%), riboflavin (0.01%), and niacin (0.03%) contents in the processed and dried shoots were found to be lower as compared to raw shoots. The content of nicotinic acid ranged from 3.87 mg to 14.92 mg/100 g in the four species of shoots, highest being in *B. nutans* [59]. Earlier work reported lower nicotinic acid content ranging from 0.20 mg to 0.80 mg/100 g [57]. The amount of pyridoxine in raw bamboo shoots ranged from 0.53 mg to 1.70 mg/100 g [59]. Edible shoots have been believed to contain considerable amounts of vitamin B12. However, it turned out that they do not contain appreciable amounts of vitamin B12; however, certain compounds showing vitamin B12-like activity (known as the alkali-resistant factor) were found in them [60].

Ascorbic acid. Many researchers have focused on determining ascorbic acid, one of the important water-soluble vitamins and antioxidant. Vitamin C content was found to be as high as 23% in a few species [15] as compared to 4%, which was reported much earlier than that [7, 57]. This kind of wide variation could be because of the mixture of shoots and leaves taken in the first study. In another report, vitamin C content for a number of bamboo species ranged from 3.0 to 12.9%, highest being in *D. hamiltonii* and lowest being in *D. sikkimensis* [12, 49]. The ascorbic acid content has been reported to increase upon fermentation of *Soibum* from 0.46% (raw) to 0.55% (5th day fermented shoot) [61]. On the other hand, the content decreased upon storage from the day of harvesting [51]. Juvenile shoots of *B. bamboos, B. tulda, D. asper, D. giganteus* and *D. hamiltonii* contained 1.90, 1.42, 3.2, 3.28 and 2.45 mg of vitamin C/100 g, respectively, as compared to 10-day-old shoots containing 1.31, 1.00, 2.12, 2.15 and 1.79 mg/100 g shoots, respectively. Further reduction in the content was observed in the canned shoots (1.8%) of *D. giganteus* followed by fermented shoots (1.09%) [51].

Fat-soluble vitamins *Vitamin A*. It is worth noting that only one researcher [7] has determined Vitamin A content (20 IU), which is very less as compared to other vegetables. It may be because bamboo shoot is a pale, white-colored vegetable and thus may not be a rich source of β carotene.

Alpha-tocopherol. α-tocopherol or vitamin E has been well known for its antioxidative properties, which play a role in preventing metabolic disorders by acting as a free radical scavenger. Very few studies involved in the quantitative analysis of this vitamin in bamboo shoots have been reported. Vitamin E content ranged from 0.61 to 0.91% and kept on reducing with older and fermented shoots. The content in juvenile shoots for *B. bamboos, B. tulda, D. asper, D. giganteus* and *D. hamiltonii* was found to be 0.61, 0.61, 0.91, 0.69 and 0.71, respectively, but it decreased to 0.24, 0.24, 0.42, 0.24 and 0.31, respectively, in 10-day-old shoots [50]. Unlike vitamin C, Vitamin E content in the shoots of *D. giganteus* decreased upon storage for 10 days (0.24%), but surprisingly, canned shoots (0.30%) were observed to have higher vitamin E content as compared to fermented shoots (0.21%) [51]. In a recent study, compounds of nutritional importance like α-tocopherol (0.26 mg/100 g), γ-tocopherol (0.42 mg/100 g), β-carotene (1.9 µg/100 g), and lutein (35.6 µg/100 g) have been reported in raw bamboo shoots [62].

Minerals

A number of the inorganic elements are regarded as absolutely essential to all of life's processes. They are supplied by the diet as salts, for example, sodium chloride. They may also be combined with organic compounds like iron in hemoglobin and sulphur in almost all proteins. They are classified as essential macro and trace (micro) elements. Macro elements are required in large amount (>100 mg/day) and present in large quantities in the body, whereas microelements are required in small quantity (<100 mg/day) and also present in small amount in tissues and body fluids. A deficiency of these elements in an otherwise nutritionally adequate diet can lead to very diverse and indefinite metabolic abnormalities [63, 64].

Macroelements *Potassium*. Potassium is a mineral involved in electrical and cellular body functions. In the body, potassium is classified as an electrolyte. As the heart is a large muscle that is continually, rhythmically contracting, potassium is extremely important to proper heart function. The K content in bamboo shoots ranges from 232 to 576 mg/100 g [55]. The content did not decrease significantly in five different species upon keeping except in *D. hamiltonii* where the content reduced to half in 10-day-old shoots [50]. Potassium content examined in fresh or frozen bamboo shoots (533 mg/100 g) decreased to 450 mg/100 g on boiling for 5–10 min. The content further decreased to 300 mg/100 g when the shoots were soaked for 2 h and boiled at 50 °C for 5–10 min [46].

Calcium. It is an important mineral required for the growth of bones. Calcium content given in early reports varied from 0.01 to 0.03% [54, 57]. Later on calcium was found to be 30–400 mg/100 g [59]. The calcium content in the mixture of leaves and shoots was in the range of 320–560 mg/100 g for different species [15]. High values of calcium ranging from 1,200 to 1,900 mg/100 g were also estimated in another report [12, 49]. The change in calcium content upon keeping the shoots was examined and found that the calcium content decreased in 10-day-old shoots. Drastic reduction took place in *D. giganteus* from 6.80 to 1.48 mg/100 g [50]. In a recent study, values ranging from 21.17 to 180.69%, highest being in *B. polymorpha* and lowest in *B. pallida* have been reported [21].

Phosphorous. It is a macroelement required along with calcium for the growth and maintenance of bones and teeth. Phosphorous content in bamboo shoots is varied. The work done during the early 1980s reported a higher value ranging from 40 to 65 mg/100 g [7, 52, 57]. Another report showed values ranging from 150 to 1,000 mg/100 g [12, 15, 49]. Processed and dried shoots have shown to possess a very high phosphorous content, i.e., 1,049 mg/100 g [43]. Significant reduction in the phosphorous content upon storage was not observed except in *D. asper* where the content decreased from 40.95 to 29.08 mg/100 g [50].

Sodium. Sodium is essential to maintain the Na–K pump and osmotic balance within the cells. Very few studies are available on the sodium content in raw bamboo shoots. The content was found to decrease drastically, i.e., three to fourfold in 10-day-old shoots as compared to the raw in all the five species tested [50]. The content remained almost the same in 10-day-old shoots (3.64 mg), fermented (3.62 mg), and canned shoots (3.24 mg) for *D. giganteus* species [51]. Amongst all the species, mixture of leaves and shoots of *Bambusa arundinacea* was found to be the richest source of sodium [15].

Magnesium. Magnesium, although a macroelement, is yet an overlooked mineral in case of bamboo shoots. It is required for contraction and relaxation of muscles and for the functioning of certain enzymes in the body. The content ranged from 5.38 to 140 mg/100 g as examined by different investigators [12, 15, 49, 50]. The content did not decrease significantly upon keeping, fermenting, and canning [50].

Trace minerals Many essential microelements like cobalt, copper, cadmium, lead, manganese, nickel, selenium, iron, and zinc have been determined in different bamboo species [50]. Among these, iron holds the prime position followed by zinc and selenium as far as nutritional importance of these elements is concerned.

Iron. Iron, though not a macroelement is an important element for the formation of RBCs and prevents diseases like anemia. Not many researchers have tried to find out the iron content in bamboo shoots. The iron content ranged from 0.1 to 3.37 mg/100 g in different species [7, 21, 50, 52]. A higher value (22 mg/100 g) was reported in processed and dried shoots [43]. The iron content was reduced in 10-day-old shoots in all the species [50].

Selenium. Selenium is essential for normal growth, fertility and for the prevention of a wide variety of diseases in animals. Selenium is a constituent of the enzyme glutathione peroxidase (GPx), a selenoprotein. This enzyme is the protective agent against the accumulation of H_2O_2 (hydrogen peroxide), and organic peroxides within cells. It is involved in immune mechanisms, ubiquinone synthesis, and mitochondrial ATP biosynthesis. Selenium has close metabolic relationship with vitamin E for curing certain diseases [64]. Selenium on the other hand was found in trace amounts (0.0003 mg/100 g) in the juvenile shoots [50].

Zinc. About 15 mg of zinc is required by an adult in a day. Like iron, zinc is absorbed according to the body's needs. The mineral is required for normal growth and sexual maturation, as part of an enzyme that transfers carbon dioxide from tissues to the lungs, the production of

insulin by the pancreas, etc. The content of zinc ranged from 0.57 to 1.01 mg/100 g shoots in five species of shoots [50].

Feasibility of integration of bamboo shoots in the family diet in non-traditional sector

Bamboo utilization has been practiced in many tropical countries for thousands of years and is considered as a cash crop mainly in the northeastern parts of India. There are many species of edible bamboo available in this region. Stewed bamboo shoots [65], pickled bamboo shoots [66], and fermented bamboo shoots [67, 68] are regarded as delicacies. Prevailing scarcity of pulses and exorbitant prices in many developing countries (including India) have deprived a large population of their protein requirements. Such a supplemental food requirement in Ethiopia has been already visualized [25]. Similarly, bamboo shoot having adequate concentration of protein, fiber, minerals, and vitamins and possessing antioxidant activity can be used in different recipes especially for young growing children and elderly for disease prevention. Dry powder of bamboo shoots, rich in protein can be easily used as condiment by subsistence families for fulfilling their protein requirements to significant extent. However, shelf life of dry powder and preservation needs to be scientifically studied.

Bamboo shoot is not only the poor man's meal but also has the potential to become an urban man's favorite. As per literature findings, bamboo shoot containing essential minerals, vitamins and dietary fiber and being low in fat helps in lowering down the blood glucose and cholesterol and can be easily integrated in several dishes made at domestic level. These findings may help in popularizing bamboo cultivation like coconut tree and herbal/medicinal plants in kitchen gardens and thus lead to integration in agro-horticultural practices.

Conclusion

Bamboo shoots no doubt form an important food source from the plant origin. Consumption in various forms is evident in the northeastern regions but it has a great potential to be incorporated in several other dishes all over the world due to its special nutritional profile. Various edible species exist in different parts of the world, which are eaten in multiple forms. Most of the studies, which have been reviewed, depict that bamboo shoots are very good reservoirs of nutrients. They are rich in protein and fiber content and low in fat content. They are good sources of vitamins like vitamin C in fermented shoots and potassium, a healthy heart mineral. In developing countries, where protein calorie malnutrition is a major problem, fermented vegetable proteins have a great potential and a ray of hope for meeting the body requirements through food supplementation. It can be judiciously integrated in the diet through various recipes or dry powder form in non-traditional sector. Food safe aspect in case of bamboo shoot can be taken care by suitable processing methods while keeping the nutrients intact. Overall potential of bamboo shoot and a new perspective for ensuring food and nutritional security in non-tribal areas is visualized.

Conflict of interest None.

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