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Bamboo shoot as a source of nutraceuticals and bioactive compounds: A review

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Bamboo has a vital importance in the lives of the native tribes and is extensively grown in varied climatic zones. It is a valuable and renewable natural resource. India is one of the richest countries in terms of bamboo resources with about 136 species. In this review, we tried to collect and systematically arrange all the available important literature on nutritional importance of bamboo with special emphasis on the traditional foods and future processing avenues. New bamboo culms that come out of the ground, called shoots are usually used in Asian cookery in various ways (raw, canned, boiled, marinated, fermented, frozen and liquid). Bamboo provides moisture (89.3 %), low fat (0.41 g/100g), high dietary fibre (3.90 %), and mineral content (1.03 %). It is also a good source of thiamine, niacin, vitamin A, vitamin B6, and vitamin E. However, they contain a potentially toxic glycoside of α -hydroxynitrile, called taxiphyllin. Trade potential of bamboo is not fully exploited, though it has the prospective to ensure livelihood security, in both rural and urban areas. As it is a seasonal product and delicate in nature, processing and preservation of bamboo products are the important steps to make bamboo accessible in developing countries. Nutraceutical potential of bamboo shoot is also explored in this review.

Keywords: Bamboo shoots, Bioactive compounds, Hydrogen cyanide, Nutraceuticals, Processing, Traditional foods

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Introduction

Health alertness among the human population is rising in such a way that there is a legitimate call for adopting a nutritionally balanced diet, with convenient use, cost, and taste[1,2]. Improved living standards and change in life style has brought a paradigm shift in the food habits of people. This trend was evident in affluent countries over a period. But, for the last decade, it is diffusing to the developing countries like India as well. Various terms such as ‗designer foods'[3], ‗functional foods'[4], and ‗nutraceuticals' have been christened to designate foods for health promotion. Largely, all refer to food or food ingredients that offer nutrition along with therapeutic or health benefits including preclusion of diseases. In Ancient time, our ancestors were well aware of certain food crops that possessed both, the nutritive and therapeutic values and hence, they integrated these foods into their customs. Until recent times, these ethnic foods were confined to smaller segments of the tribal communities across the world. Bamboo is one among those native food crops, which has long history for its value in traditional diet of various tribes[5-7].

Bamboo is an evergreen flowering plant belonging to the family Poaceae[6]. Bamboo shoots, with their high nutritive value, hold huge promise for deployment as a healthy food. The phenology of bamboos renders them resistant to biotic and abiotic stresses. Layers of tightly clasped sheaths protect bamboo from pollution[6-8]. With its abundance, bamboo has a significant role in improving the livelihoods across society and culture[8-11]. Japanese use the leaves as fodder and shoots as bio insecticides[6,8,12-14]. Giant pandas of China also like to eat bamboo shoot[13,15]. Many bamboo species are readily used in landscaping to adorn homes and gardens[16-19]. Bamboo could easily prevent soil erosion with its interwoven rhizome system and roots and thereby helps in enrichment of carbon in soil[8,9,12-14].

Due to its multidimensional uses, bamboo has been called as ‗The cradle to coffin plant'[16], ‗The poor man's timber', ‗Friend of the people', ‗green gasoline'[20-22], ‗The plant with thousand faces'[20] and

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‗The green gold'[22]. Bamboos are used in more than 1500 different traditional ways[14,16,17] from all over the world. Bamboo shoots are used lavishly in Asian cuisine and are available in supermarkets as fresh and canned products[10,17,20]. Bamboo shoots are recognized as source of high dietary fibre and mineral content with lower amounts of fat. Tribal people used it as an ideal vegetable[6]. Bamboo curry, chutney, candy, pickle, fried shoots, canned bamboo juice, and bamboo beers are poplar foodstuffs made from bamboo shoots[19]. Bamboo vinegar is used for flavouring vegetables[18]. Various fermented bamboo products are very popular in different states of the North Eastern region of India[6,11].

In spite of its medicinal properties and popularity among tribals, very little attention has been paid by younger generation[6,20,22-24]. This review paper, therefore tries to look into the insight of bamboo with the main focus on its value addition, nutritive and economic value in a holistic way. The studies on anti nutritional constituents present in different bamboo shoot species by various investigators have also been discussed. Chances of integrating this traditional food in to the modern lifestyle have been looked into. Finally, the thrust areas to be focused are also explored for future research.

Global distribution of bamboo

Bamboo has emerged as one of the important Non-Timber Forest Products (NTFP) in the world. It can grow lucratively on fallow and waste lands with minimum inputs[6,7]. The plant is mostly distributed in the tropical, subtropical, and temperate zones of the world. About 1,575 species belonging to 75 genera are being reported worldwide out of which 320 species are confined to tropical zone. The bamboo rich country China contributes 300 species followed by Japan with 237 species[21, 25-27]. In India, 136 species spreading in 36 genera are found. North east alone becomes land for 58 species belonging to 10 genera[6, 22]. Other than these countries, Burma (90), Philippines (55), Thailand (50), Malaysia (44), Bangladesh (33), Indonesia (31), Nepal and Sri Lanka (30 each) are reservoir of bamboo diversity[21]. India with 10.03 million ha (12.8 %) area under bamboo cultivation of the total forest area, stands second to China, producing 32.3 million tons of bamboo shoots[28]. The predominant species in India are *Dendrocalamus longispathus, D. brandisii, Bambusa balcooa, B. polymorpha, B. pallid*, and *Melocanna baccifera*[7] in North East, *Arundinaria* spp., *B. arundinacea, B. glaucescens, B. longispiculata, B. vulgaris, Cephalostachyum capitatum, C. fuchsianum, D. hookeri*, and *Oxytenanthera albociliata* in Southern India[29], and *D. strictus* and *B. bambos* in central India. From Thailand, species like *B. nutans, B. tulda, D. giganteus*, and *D. hamiltonii. Dendrocalamus asper* has been introduced to India[13,28].

Tender, immature, and young stalks emerging from the nodes of the pseudo rhizome is called bamboo shoot. It grows to a length of 20-30 cm tapering towards tip giving a conical shape. Each shoot weighs more than 1 kg at the time of harvesting[27] (Plate 1). However, their size and weight depend considerably

Plate 1 — Road side selling of fresh bamboo shoots in Imphal, Manipur

upon species, soil and climate[28]. Edible new bamboo shoots mostly emerge in winter (November-December) and spring (February-March). As compared to the winter shoots, the spring shoots are larger and tougher. The shooting period of bamboo differs from species to species. In general, the temperate-climate-bamboos are runners, which shoot in the spring, while mostly clumpers are emerged during the tropical and sub-tropical conditions, which shoot in the late summer and autumn[6,22,29,30]. Outer layer of the shoot is tough, hence it is peeled off to catch tender white coloured fraction of the shoot. Its tender crunchy texture and delicate flavor is priced by connoisseurs. They come in both fresh and canned forms although the canned bamboo shoots are easier to find as compared to the fresh ones.

The edible part of bamboo shoot consists of meristematic tissue with regions of rapid cell division and differentiation, enveloped in protective, non-edible leaf sheaths[26]. They are soft, crispy, generally ivory yellow or white in colour which turns yellow when cooked. The sheaths covering the shoots are black, brown, yellow, or purple[11,19,31,32]. Fresh bamboo shoots at tender stage resemble coiled springs, have good flavor and texture. It is an excellent source of vitamins, carbohydrates, proteins, and minerals. Daily use of these shoots helps the rural poor to evade ill effects of malnutrition[32].

Nutraceutical importance of bamboo shoots

Due to the widely grown health concern and side effects of allopathic system of medicine among the people, natural foods rich in nutraceuticals are catching up very fast. Bamboo shoots have greater role in pharmaceutical, food processing and beverage industries. The nutritional value of edible shoots of different bamboo species has been worked out by several workers[7,32-42]. Chemical composition of edible bamboo shoots is presented in table 1. Bamboo shoots are considered as nutritional foods as they supply protein, carbohydrates, amino acids, fat, sugar, fiber, and inorganic salts in considerable quantities. Fresh shoots are an excellent source of vitamin A, vitamin B complex (B6, thiamine, niacin), vitamin E, and dietary fibers like hemicelluloses, cellulose, pectin, and lignin[34,43]. These are healthy foods as the shoots contain low fat, cholesterol, (0.26-0.94 %), and important essential fatty acids. Total fat content in bamboo is 0.5 %, on the contrary, they are rich in carbohydrate (5.70 %), protein (3.9 %), and moisture (88.8 %)[38,39,40]. Bamboo shoots are good source of edible fiber (6-8 g/100 g fresh weight) and phytosterols, which helps in lowering the blood cholesterol. The total sugar content (2.5 % on average), is lower than most of the other vegetables and therefore, can be used as a component of sugar-restricted diets.

Potassium is an important mineral to both cellular and electrical functions. Barring spinach and potatoes, bamboo shoot has a comparatively higher K content (620-1100 mg/100 g)[7,12,38]. Magnesium, which plays an indispensable role in body metabolism is also highest in the shoots of *D. giganteus* (10.09 mg/100 g) like Brinjal (10.0 mg/100 g fresh weight). Selenium, a miracle element, is also present in some species of bamboo shoots. They contain 17 amino acids, 8 of which are essential for the human body[43]. Tyrosine, amounts from 57 to 67 % of the total amino acid content[40-45]. Shoots of *B. bambos* contain secondary metabolites like glucosides, choline, cyanogens, and betain which are used to cure diarrhoea and, cough[37,43,44,46-49]. Taste of bamboo depends on the total sugar, total amino acid (aspartic acid (Asp), glutamic acid (Glu), glycine (Gly), and tannins[39,44,49,50].

Therapeutic properties

Bamboo shoots have a wide range of health benefits, from cancer prevention and weight loss to improving appetite and digestion[51]. Bamboo shoots have been regarded as a customary medicinal constituent for more than 2000 years, according to archaic Chinese medicinal books, such as *Ben Chao*

Table 1 — Proximate analysis on selected species of bamboo shoots[15,113]

Species	Moisture (%)	Minerals (as total ash) %	Phosphorus (mg/100 g)	Calcium (mg/100 g)	Iron (mg/100 g)	HCN (%)
Bambusa balcooa	91.48	0.99	30.99	24.01	1.04	0.071
B. pallida	92.29	1.12	32.27	21.17	1.16	0.106
B. polymorpha	91.65	0.91	15.06	180.69	1.44	0.032
Dendrocalamus strictus	85.98	1.14	58.13	139.5	2.74	0.133
D. hamiltonii	92.37	1.01	27.76	44.16	1.65	0.071
D. giganteus	91.19	0.89	12.57	26.93	1.09	0.044
Melocanna bambusoides	91.22	0.98	14.28	47.58	0.89	0.056

Qui Zheng and *Ben Jing Feng Yuan*. Bamboo shoots are proclaimed to be beneficial to human health, by promoting motion and peristalsis of the intestine, helping digestion, preventing and curing cardiovascular diseases (CVDs) and cancers[19,23,51-54]. However, not much scientific research have been done to prove these claims until now[24,47,49,50]. Protease activity responsible for digestion got increased with juice intake[51,55]. Boiled bamboo shoots are used as appetizers and the decoction of shoots are used for cleaning wounds and maggot infected sores, ulcers[54,56,57]. Bamboo is an ingredient in many steroidal drugs due to its antimicrobial properties[24,52,58]. Salt tablets made of bamboo are known to help in treating internal maladies in Korea[34]. It serves as a natural detoxifying agent and also provides energy and nutrients to the body. In Java, sap from inside the shoots of *B. vulgaris* is used for curing jaundice. In the traditional system of Indian medicine, the siliceious concretions found in the shoots are called *banslochan*; and in the Indo-Persian and Tibetan system of medicine, it is called *tabashir* or *tawashir*; in English, it is commonly known as bamboo manna[21] obtained from *M. bambusoides* and *Bambusa arundinacea* for its unique healing properties[24, 59].

Bioactive compounds

With the prospects of feeding a fast growing population in the 21st century, agriculture by-products can be used as a source of valuable nutraceuticals[2,3,56]. All parts of bamboo plants contain bioactive compounds at varying concentrations[57-60]. Bamboo shoots are rich source of antioxidant compounds like flavonoids, phenols, and phenolic acids[11,58,61]. Lignins, key ingredients in dietary fibre, possess anticancer, antibacterial, and antiviral activities. These compounds are found in considerable amounts in the bamboo shoots[29,62-66]. Dendrocin, an idiosyncratic anti-fungal protein is isolated from bamboo shoots[19]. Phenolic compounds have the potential to act as antioxidants and inhibit the lipid peroxidation in biological systems. Eight phenolic acids are present in bamboo shoots of *Phyllostachys pubescence.* Among them, protocatechuic acid, p-hydroxybenzoic acid, and syringic acid were found to be most abundant[62]. From bamboo, several antimicrobials and antioxidants have been isolated through supercritical CO_2, followed by subsequent hydrothermal treatment, including an ethoxyquin and a cyclohexanone derivative. The shoots also contain anti-carcinogenic agents; regular intake will competently scavenge the free radicals producing destructive carcinogens. A study revealed that pyrolysates from *Phyllostachys bambusoides*, *P. nigra*, and *P. pubescens* may have anti apoptotic effects and could be used to heal ischemic injury[66]. Sitosterol, an abundant polysterol detected in fermented shoots offers easy microbiological conversion in the synthesis of estrone and renders excellent health[67-70].

Numerous methods have been developed for extraction of bioactive compounds from bamboo shoots. The concentration of solvent should be at optimum level to avoid loss of bioactive compounds. Among them, 60-80 % (v/v) ethanol concentration was proven to be economical. Ethanol concentration had major effects on the yields of total phenol content (TPC), total flavonoid content (TFC), DPPH radical scavenging capacity, flavonolgallates, and iriflophenone 3-C-*β*-glucoside concentrations[51,56]. Phenolic acids like gallic acid, caffeic acid, and vanillic acid are also detected in most of the bamboo species[50]. *Bambusa textilis* Mc Clure is used to treat chronic fever and infectious diseases. Three potential bioactive compounds, including (*E*)-*p* coumaric acid, (*Z*)-*p*-coumaric acid, and apigenin-8-*C*-β-D-(2"-*O*-α-L-rhamnosyl)-glucopyranoside were detected in both the leaves and shoots of *B. textilis* as identified through NMR spectra[53].

Market prospect of bamboo based foods

Bamboo shoots are consumed in various forms from dried to fermented, including as medicine[2,11,16,67-73]. The estimated business of bamboo in global markets is around $10 billion[2,51,73]. Average annual consumption of edible bamboo shoots is around two million tones throughout the world[74-77]. With INR 26,000 million economy by 2020 from the current INR 2,000 million in India, bamboo has great scope to provide the livelihood development of five million families[5,6,78-81].

USA, being the major consumer, imports around 44,000 tons of bamboo shoots accounting for 14.5% of the total world import[5,6,80]. Australia imports about 8,000 tons/year[9,81]. China gains 6,500 million INR annually through trade of edible bamboo shoots. Canned shoots are most preferred processed form consumed in Singapore, but frozen cooked shoots are also consumed[75]. With the cultivated area of 0.30 lakh ha, Taiwan consumes about 3,80,000 tons of bamboo shoots annually. From 1.2 kg/year in 1950s, Japan consumption has increased to about 3 kg/year per person[78]. Bamboo shoot exports from Taiwan and Thailand worth 250 and 150 crore/year, respectively meet the demand of Japan[79-83].

Preservation of bamboo shoots

Fresh bamboo shoot is a vigorously growing plant part with higher metabolic activities when attached with mother clump. Therefore, once it is detached from the mother plant, the external factors like temperature, humidity, storage conditions, and microorganisms significantly affect the keeping quality[24,42,81]. With the loss of water, the freshness of bamboo deteriorates drastically and thus, the quality[44]. An earlier study suggested that the bamboo shoots become prone to hydrolysis with the increased enzyme activity and saccharine content, thus, made them susceptible faster to rotting and infection to postharvest diseases[54].

Respiration (>4.08 mmol CO_2/kg/h) and transpiration of harvested bamboo shoots elevate with the higher temperature (20 °C) during storage and transit[82]. Low temperature storage is therefore required to enhance the shelf life and to inhibit water transpiration and microbial activity. Preserving in 10-20 % salt solution[55,59,66]; minimal processing and devoid of light are some of the options for preservation of bamboo shoots. Research has emphasized the requirement of low temperature and proper packaging to reduce transpiration losses of bamboo shoot[84]. Bamboo shoots fiber content increases from the cut end to tip after harvest. This leads to deterioration of quality. The formation of fiber could be reduced by high RH coupled with low temperature[82]. Wounding and minimal processing, induced respiration rate, PAL, PPO activity Malondialdehyde (MDA) content and phenolic compounds, but decreased sugars, lignin, and cellulose contents[85] in apical, middle, and basal sections of bamboo shoots. The MDA content increased sharply after processing and remained at high level during storage[54,86].

Forced-air cooling, hydro cooling combined with forced-air cooling, vacuum cooling combined with hydro cooling and vacuum drying process are widely used to preserve bamboo shoots. A multi-stage vacuum pressure preserving technique combined with hydro cooling can reduce the temperature of bamboo shoots[88]. Bamboo shoots (*Phyllostachys praecox* f. *prevelnalis*) stored at 10 °C under MAP (0.04 mm thick LDPE bag, 2 % O_2, 5 % CO_2, and 93 % N_2) recorded lower malondialdehyde (MDA) content than the control during early storage[89]. Lignification was also reduced by MAP by preventing the formation of cellulose and lignin. Research has revealed that the shelf life of shoots can be extended to one month by storing at 1 °C in semi-permeable, micro-perforated LPDE film[90].

Antinutritional compounds and its removal

Bamboo shoots are soft and crispy and should therefore be harvested soon after their emergence. Delayed harvesting may lead to development of an unpleasant flavor which is due to presence of cyanides[89]. Results revealed that the giant bamboo contains cyanide in more quantities. Cyanogenic glycosides are nitrogeneous phytoanticipins, major players in defense mechanism of plants against predators[90,91]. They contain a potentially toxic glycoside of α-hydroxynitrile, called as taxiphyllin. It is activated by the action of hydrolytic enzyme, α-glycosidase on disruption of the plant cell[92-95]. The content of cyanogenic glycosides has been assessed by various researchers[96-99] and mechanism responsible for the formation of HCN has been formulated[95]. It includes the degradation of cyanogenic glycosides followed by production of HCN in the presence of α-cyanoalanine synthase. As the biosynthesis pathway is beyond the scope of this review papers, interested readers may refer the research works of various researchers as quoted elsewhere.

A bamboo shoot constitutes free cyanide at levels (approximately 50–60 mg) that are fatal for an adult man[100]. Older shoots build up more cyanogens, whereas the younger shoots possess nil or negligible amounts. Consumption of raw or under processed bamboo shoots may lead to drop in blood pressure, dizziness, stomach pain, and head ache[97]. Bamboo shoots contain 0.3 to 0.8 % HCN[95,93]. High HCN content (0.16 %) is detected in the tip and it is reduced (0.01 %) at the base[90]. The quantity of cyanides in edible bamboo shoots is mentioned in table 1. Its content varies with the species. The amount of cyanides is 894 mg/kg in *Dendrocalamus giganteus*[22,100], 0.14 mg/g in *M. bambusoides*, and 0.04 mg/g in *B. pallida*. Higher cyanogenic glucoside content of 200 and 386 mg/Kg fresh weight were detected in raw bamboo shoots of *B. vulgaris* and *D. strictus*.

Methods of removing HCN from bamboo shoots, before consuming them include boiling, canning, soaking, and fermentation. Processing helps in reducing the cyanide concentration. Normally, incomplete cooking resulted in hydrolysis of glycoside followed by release of HCN[100,101]. Boiling bamboo shoots for 20 min at 98 °C excludes 70 % of HCN and about 96% is removed by boiling at this temperature for 2-3 hours[100,102]. Subsequently, Tripathi[29] mentioned that exclusion of HCN is possible through steaming bamboo

shoots. It is reported that pre soaking of shoots for long time in water and 2 % salt solution changing them frequently in a sequential manner is a feasible method to remove HCN[50]. It is also reported that superheated steam drying under low temperature removes HCN from bamboo shoot as taxiphyllin decomposes at around 116 ^{o}C[106]. Earlier study has reported that canning, osmotic dehydration, and drying bamboo after shredding drastically reduced the HCN content[108].

It has been reported that cyanide content is reduced with prolonged fermentation at low pH and due to microbial activity. Surprisingly, literature is silent on the effect of preservation and storage on the toxic content in bamboo shoot. Satya *et al.*[7] reported significant reduction (up to 82.7 %) in toxicity of *B. balcooa* and *B. tulda* when stored at −18 °C for 2 months. Cyanide content, is reported to decrease largely after harvesting[40]. Different indigenous methods to reduce acridity in bamboo shoots have been reported, which include chopping of tender shoots into small pieces, partial drying of fresh shoots, boiling in water/salt water and draining; keeping shoots in hot water for 10–15 min; or in water for a week at ambient temperature[24,107]. *Adi* women of Arunachal Pradesh used banana leaves for semi-fermentation of shoots and pressed under stones near water stream for 3-4 months to reduce bitterness[107,109].

Bamboo processing: Traditional and modern methods

Processing and value addition refers to any change in the physical form of the product that adds value for the product thereby increasing its utility and price in the market. Bamboo shoots are utilized to make different kind of value added products (Fig. 1). Value added products of edible bamboo shoots will not only generate good revenue, but also mobilise farmers to go for its cultivation on commercial scale.

Traditional bamboo based food products, fermented and unfermented beverages

In North East part of India, bamboo is integrated in daily life of tribal people (Table 2). Various tribes have indigenous food preparation using bamboo shoots extensively. *Byapu, Papu Sududanii* (egg is poured into the bamboo shoots), *Paroyo Sududanii* (with chicken) are the most common bamboo products of *Apatani* tribe[30,32,100,108-110]. The consumption of fermented, roasted, and boiled shoots was estimated to be the highest in Arunachal Pradesh (481 tonnes/year) and the lowest in Nagaland (19.5 tonnes/year). Major species used for fermentation include *B. tulda*, *B. vulgaris*, *B balcooa*, *B. pallida*, *D. hamiltonii*, *D. hookeri*, *D. flagellifer*, *D. giganteus*, and *M. baccifera*[108,109]. Tamang *et al.*[32] attempted to explore the traditional knowledge of biopreservation of bamboo shoots in Northeast India. Lactic acid fermentation is the main mechanism involved in the bio preservation process by lowering the pH and increasing the acidity of products by soaking the 0.5 cm thick slices for 24-36 h. *Mesu* is a traditional fermented bamboo shoot pickle with sour acidic taste, which is popular in Sikkim and Darjeeling hills of India[112]. *L. plantorum, L. brevis, L. curvatus, Leuconostoc citreum, Pedicoccus pentosaceus* are believed to be responsible for fermentation (Plate 2).

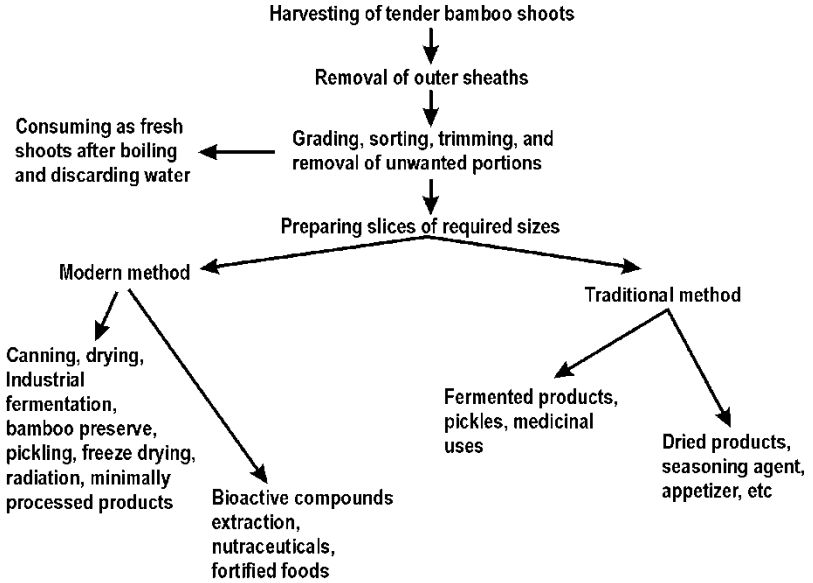

Fig. 1 — Outline of bamboo shoot processing[5,6,12]

Table 2 — Traditional bamboo shoot products being produced in different states of India

ıl name of the recipe	State/Country	Mode of preparation	References
Khorisa	Assam	Fermented bamboo product	100, 102
Kardi	Orissa	Fermented bamboo product	6, 29
Byapu, Papu Sududanii,	Arunachal Pradesh	Prepared by egg yolk poured into the bamboo shoots.	101, 102, 103, 104
Paroyo Sududanii	Arunachal Pradesh	Prepared by pouring chicken soup into the bamboo shoots are the popular dishes of Atapani tribe.	30, 6, 100, 32, 110
Ekung	Arunachal Pradesh	Popular fermented product from *Nishi* tribes. Mostly prepared from tender shoots of *Dendrocalamus hamiltonii, D. giganteus, Bambusa balcoa, Phyllostachys assamica*	30, 6, 100, 32, 110
Mesu	Arunachal Pradesh	Traditional fermented bamboo shoot pickle with sour acidic taste of Tawang region	100, 6, 5
Pu-erh	Sikkim and Darjelling	Tea prepared by pouring steamed tea in bamboo hollows	29
Soibum& Soidon	Manipur	Fermented product prepared from inner white portion of tender bamboo shoots	28-30, 112
Tenga, Lung-siej	Meghalaya	The tender bamboo shoots of (*Dendrocalamus hamiltonii*) are cut in to strips and fermented for a week	*112, 29, 38, 39, 15*

Plate 2 — Ethnic fermented products from tender Bamboo shoots in Arunachal Pradesh[12,129]

Soibum and *Soidon* are the most popular fermented product prepared from inner white portion of tender bamboo shoots and is consumed in North Eastern India, especially in Manipur[29,38,39]. The shoots of *Dendrocalamus hamiltonii, D. sikkimensis, Bambusa tulda, B. balcooa* are commonly used. The tender bamboo shoots of are cut in to strips after removing the outer green colour sheaths and fermented for a week after boiling to prepare products called *Tenga,* and *Lung-siej*, which are most common ethnic food of Meghalaya[113-115]. *Lung-siej* contain high fat, iron, and magnesium levels (0.6 mg, 8.5 mg/100 g, and 294mg/100g, respectively) on fresh weight basis. *Ekung*, a popular fermented product of *Nishi* tribes of Arunachal Pradesh is mostly prepared from tender shoots of *Dendrocalamus hamiltonii, D. giganteus, Bambusa balcooa, Phyllostachys assamica* by tightly covering the bamboo baskets that are kept under ground after 2-3 months of fermentation. The bamboo baskets are laid in the previously dug pits and lined with leaves and then sealed. Stones are kept in the top to drain excess water from the bamboo shoots and fermented for 3 months and stored in air tight container for year. *Bacillus subtilis, B. licheniformis, B. coagulans*, *Micrococcus luteus*[29,100], *L.plantarum, L, bervis, L. casei and Tetragenococcus halophilus* are some of the organisms involved in fermentation. This can be stored up to 3 years without reduction in quality of the produce.

Fermented form of bamboo shoot is an important ingredient in cuisines of Himalayas. In Assam, it is called *khorisa* and *Kardi* in Orissa. *Alu tama* (a recipe

from Nepal with bamboo shoot, turmeric, and potato) and *gulai rebung*, (thin slices of bamboo, coconut milk and spices from Indonesia) are popular dishes[29,100]. *Sayur lodeh* (mixed vegetables in coconut milk) and *lun pia* (fried wrapped bamboo shoots with vegetables) are other recipes prepared using bamboo shoots. The pith of the young shoots is used in making pickled bamboo which is used as a condiment[116]. This fermented bamboo shoot is used in various culinary preparations and is notably added to a sour vegetable soup called the *amil*.

The dried products like *Ipe, Eup* are grounded into fine powder that is used in preparations of many cuisines of Arunachal Pradesh. *Hirring* or *huch* or *hitak* is also a fermented bamboo shoot prepared by the *Apatani* tribes of Arunachal Pradesh[113,117]. The prepared product has 52.1 % carbohydrate and energy value of 363.0 kcal/100 g. Only tips of the tender bamboo are either cut longitudinally into 2-3 pieces or whole shoots are flattened by crushing and are kept in bamboo baskets lined with leaves. The prepared product has 0.81 % acidity, 2.7 % fat (DWB), 49.3 % carbohydrate, and food value of 353.5 kcal/100 g [77,115]. In fermented bamboo, the contents of protein were significantly higher (8.5 g/100 g) in comparison to 3.9 g/100 g in unfermented bamboo shoots due to the presence of microorganisms, which grow during the process of fermentation. With a characteristic bamboo aroma and beer flavor, bamboo juice beers show a good number of health benefits by lowering blood lipids and fighting heart ailments[34].

Fermented, dried products of bamboo are most popular in South East Asian countries (Table 3). *Ma khua proh* is the popular ethnic food of Thailand prepared by mixing bamboo shoot, pea, and pumpkin. *Dom jud naomai* is the pork based bamboo shoot soup very popular in Thailand. The sap of young stalks tapped during the rainy season may be fermented to make *ulanzi* (a sweet wine) or simply made into a soft drink. Baby shoots (Nepal: *tusa*), pickled bamboo shoots (Nepal: *tama*) are cooked as curries with beans[109]. Fresh bamboo shoots are sliced and pickled as like any other pickle by keeping the glass jar in direct sunlight. Similarly, *Pu-erh* tea is prepared by pouring steamed tea in bamboo hollows. In Vietnamese cuisine, shredded bamboo shoots are used alone or with other vegetables in many stir-fried vegetable dishes. It may also be used as the sole vegetable ingredient in pork chop soup. Two most popular Philippine recipes ‗*ginataang labong*' (*labong* with coconut milk and chilies) and ‗*dinengdeng na labong'* (*labong* in fish *bagoong* with string beans, *saluyot*, and *tinapa*) are prepared with bamboo shoots[113-115].

Modern methods of processing

Dried bamboo shoots

Dehydrated bamboo has lot of demand in the market and gets premium price. Hence, it is widely used for processing bamboo though it is a tedious process, as it requires fine chopping of bamboo shoots[113,117,118]. Dried bamboo chops are used in conventional recipes. Extensive research has been done to develop drying technologies for various commodities (Plate 3). However, very little work is reported on drying of bamboo shoots. Upon drying, the moisture content of fresh bamboo shoots goes

Table 3 — Bamboo shoot based products of various countries around the world

Local name of the recipe	Country	Mode of preparation	Reference
Alu tama	Nepal	Recipe with bamboo shoot, turmeric and oil cooked with potato that usually accompanies rice	29, 30, 112
Ulanzi	Nepal	The sap of young stalks tapped during the rainy season may be fermented to make (a sweet wine) or simply made into a soft drink.	109
Tusa	Nepal	Pickled baby bamboo shoots	109, 108
Tama	Nepal	Shoots are cooked as curries with beans	114, 115, 113
Gulai rebung		Thin slices of bamboo boiled in thick coconut milk adding spices.	113
Sayur lodeh	Indonesia	Boiling bamboo slices in coconut milk with mixed vegetables.	
Lun pia		Fried and wrapped bamboo shoots along with vegetables	
Ginataang labong		*labong/Bamboo* with coconut milk and chilies	112, 29, 34,
Dinengdeng na labong	Philippines	*labong* in fish *bagoong* with string beans, *saluyot*, and *tinapa*	116, 112
Amil		Fermented bamboo in sour vegetable soup	
	Vietnam	Shredded bamboo shoots are used alone or with other vegetables in many stir-fried vegetable dishes. It may also be used as the sole vegetable ingredient in pork chop soup	
Ma khua proh	Thailand	Ethnic food Prepared by mixing bamboo shoot, pea and pumpkin.	29, 8, 100, 112
Dom jud naomai		Pork based bamboo shoot soup	

Plate 3 — Bamboo shoot prepared for sun drying[54,97]

down from 92 to 5 % per 100 g weight[119]. In recent times, bamboo shoot is blanched after slicing into small pieces in hot water to reduce its enzymatic activity and is treated with KMS (1 %) for 10 min. Then it is sun dried or cabinet dried and packed in an air tight container[113,119]. Osmotic dehydration of bamboo is also tried to extend the palatability of dried bamboo shoots (Plate 4). The sugar concentration of 55-58 ^{o}B with slice thickness equal to 8 mm and fruit to syrup ratio with 1:4 at 55 ^{o}C, are found to be optimum for osmotic dehydration of bamboo slices[119-121]. Bamboo preserve, bamboo pickles, and bamboo candies are some of the other industrial products being produced from bamboo shoots. Quality attributes of end product using multi-stage drying technologies, such as solar-assisted heat pump drying, solar drying with thermal energy storage, microwave assisted vacuum drying[43], refractive drying and supper heated steam drying may be tested for drying bamboo shoots[100,105,107,108].

Bamboo canning

Canning was first used by Japanese to preserve fresh shoots. The shoots are cut in various ways—into halves, thin slices, strips, diced, or canned as whole after processing[122]. Superior quality canned bamboo shoots are obtained by vacuum processing. To gain good quality products, the bamboos are sliced and boiled in water for about 1-4 hours at 120 °C. Then cooled and stored in 1 % citric acid and 5-10 % brine solution depending on the species. More than 50 branded canned bamboo products are being manufactured by over 100 companies throughout the world. China, Taiwan, and Thailand are the major players in the global trade. There is a vast demand for these products in Singapore, Malaysia, Vietnam, United States, Canada, Europe, Australia, and New Zealand[92]. In India, there are a few companies that imports and markets canned bamboo shoots from Bhutan and Thailand. Despite the draw backs like high cost, poor texture and crunchiness, loss of aroma and poor shelf life in open condition, the ease in usage and availability are the main reasons that some hotels and restaurants prefer canned bamboo to fresh products. However, except for the dietary fiber, there is an overall decrease of the nutrient components, especially vitamins and minerals, during canning[113,127].

Bamboo powder

Bamboo shoot powder could be directly used in items like dry foods and beverages[105,123] as they are low in moisture, free flowing, and easy to handle[85]. It is added as an essence in cookies and mixing 3-8 % of bamboo powder is common in preparation of any food items in Japan. Bamboo shoot contains considerable amount of carbohydrate and dietary fiber. During boiling, the polysaccharides get hydrolyzed into simple sugars and gives sweet taste to the shoots[39].

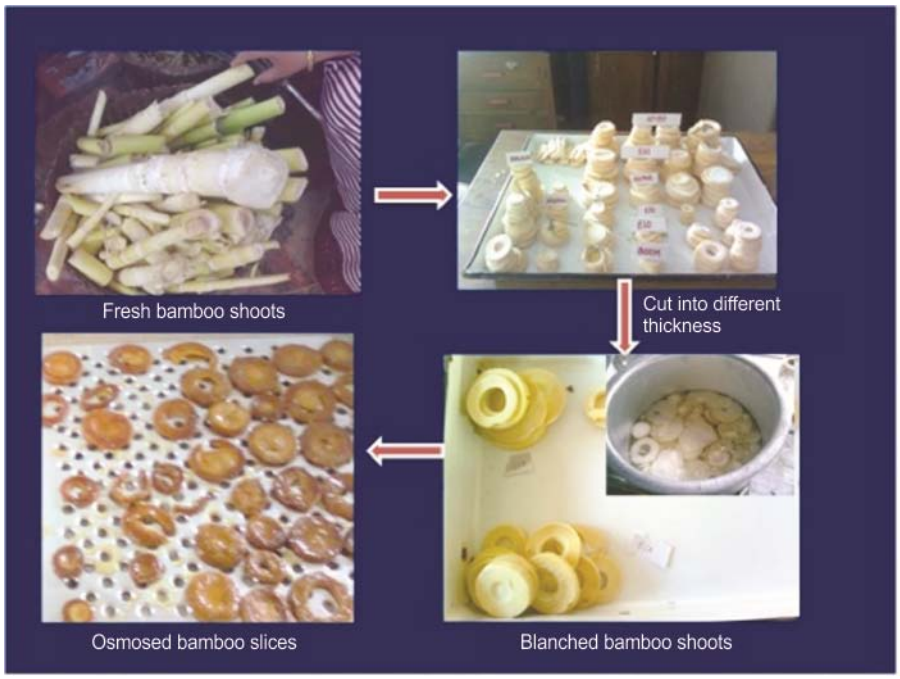

Plate 4-Osmotic dehydration of bamboo slices[113,119]

Quality changes during and after processing

Processing may bring marked changes in nutrient content in the original product, by altering the physical and chemical composition during the process. Protein, sugar, and ash contents in the shoots decrease after boiling. Ash content reduced 18-20 % after boiling, 15-17 % after canning, and 12-15 % after fermentation. The carbohydrate content increased from 4 to 7 g/100 g fresh weight after boiling, which accounted for 70 % increase in content after fermentation and canning[40]. The fiber content normally did not change after boiling[39]. However, it increased considerably after fermentation and canning. Research has revealed that the fresh shoots of *D. giganteus* have higher quantities of macronutrients such as amino acids, proteins, carbohydrates when compared to fermented and canned shoots, except for vitamins C and E and minerals[43]. As discussed earlier, like any other crop, the nutrients and minerals tend to lose with processing. Raw shoots recorded higher Vitamin C and E content (3.28 mg and 0.69 mg/100 g FWB) than the canned (1.8 mg and 0.3 mg/100 g FWB) and fermented shoots (1.09 mg and 0.21 mg/100 g FWB). A study conducted on 5 commercially important bamboos, *D. hamiltonii, D. asper*, *B. tulda*, *B. bambos,* and *D. giganteus* revealed that with aging the nutrient components of the shoots depleted, where as the dietary fiber and moisture contents increased. This exemplified that freshly emerging shoots are nutritionally superior to the older emerged shoots[106].

Future prospects

Scientific and technological advances in food industry, awareness on personal health, increase in expenditure on health, busy lifestyles, inadequate physical exercise have triggered the need for innovations in the field of functional food research[124-126]. Other than alleviating hunger, foods also provide necessary nutrients and impart immunity to nutrition-related disorders. Bamboo shoots are identified as foods with both nutraceutical and aesthetic value. It captures a novel place in the spectrum of plant foods to add essence to our diet and also to enhance the eminence of life. Bamboo shoots hold the prospect at industrial and society levels[127]. Till today, different bamboo based products are prepared by traditional methods to cater the needs of the local people. Hence, they are restricted to the choice and taste of the local consumers only. There is no standardized protocol for preparation of the raw bamboo shoots into commercially important value added products, their preservation, and value addition[6,128]. This invites policy makers for the development of appropriate technologies for preservation of bamboo shoots. In India, there is yet neither major approach for promotion of raw or processed bamboo shoots nor there is well intended market or supply chain for them.

Present sources of phytosterols, which are bracketed as functional foods are being derived from vegetables. Bamboo, being a fast growing plant can be an important source of phytosterols. The bamboo shoot-based industry is gaining popularity in South East Asian countries and generating good income for the growers[24,125]. India has an extensive price advantage in edible bamboo exports[127]. Fresh bamboo shoots fetch US dollar 0.23 to 0.27/kg during the peak season in the local markets. Bamboo prices range from US dollar 1.5 to 3 in Japan. The price raises up to US dollar 4 to 6/kg during off season. The following aspects should be focused for sustainable development of bamboo shoot-based industries, (i) screening and selection of suitable bamboo species for cultivation and value addition of various products[6], (ii) scientific management of bamboo for commercial exploitation and bio-prospecting and standardization of extraction procedures for bioactive compounds, (iii) standardization of appropriate processing and value addition technologies; pre and postharvest management of bamboo shoots[109], (iv) optimum utilization of bamboo shoots as potential source of nutraceuticals[124], (v) minimal processing and identification of packaging methods for products[128-131], (vi) standardization of equipment design and product manufacturing, (vii) identification of niche markets and developing blended bamboo based products, and (viii) policy initiatives for bamboo growers and processors.

Conclusion

The increase in consumer‘s income and awareness of nutritional benefits of different foods demands the need for search of diverse food crops. Nowadays, consumers are more conscious about the food quality, safety, and the environmental conditions under which it is produced. Bamboo shoots could be a better nutritional supplement under these circumstances. Bamboo is an integral part of lives of many tribes worldwide. Bamboo shoots in fresh or processed form serve as sustainable food source for them since time immemorial. But surprisingly researchers/scientific community did not show much interest in this crop, which is not only a valuable nutraceutical, but also has an enormous export potential[129-131]. Food safety and security can be achieved by traditional knowledge coupled with scientific interventions/scientific evaluation. Integration of conventional and modern technologies may be a powerful tool for making affordable food to poor farmers and consumers. These approaches make developing countries to be a market-driven economy from a traditional economy. As a soil conservative crop, it does require little investment and attention for cultivation. Development of different processed products from bamboo shoots combining indigenous knowledge and modern processing techniques is a step forward towards sustainable development of the rural poor. Bamboo is a rich source of bioactive compounds that need to be exploited for industrial purpose. Bamboo based tourism, food expos, green energy, bio technology are the other thrust areas to be taken care of for income generation and livelihood development of the poor without disturbing the bio diversity.

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