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Nutritional Properties of Bamboo Shoots: Potential and Prospects for Utilization as a Health Food

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Abstract: Bamboo is intricately associated with humans from times immemorial. Popularly known for their industrial uses, a lesser known fact of bamboos is the usage of its young shoots as a food that can be consumed fresh, fermented, or canned. The juvenile shoots are not only delicious but are rich in nutrient components, mainly proteins, carbohydrates, minerals, and fiber and are low in fat and sugars. In addition, they contain phytosterols and a high amount of fiber that can be labeled as nutraceuticals or natural medicines that are attracting the attention of health advocates and scientists alike. The shoots are free from residual toxicity and grow without the application of fertilizers. Modern research has revealed that bamboo shoots have a number of health benefits: improving appetite and digestion, weight loss, and curing cardiovascular diseases and cancer. The shoots are reported to have anticancer, antibacterial, and antiviral activity. Shoots have antioxidant capacity due to the presence of phenolic compounds. The increasing trends of health consciousness among consumers have stimulated the field of functional foods and bamboo shoots can be one of them. Bamboo fiber is now a common ingredient in breakfast cereals, fruit juices, bakery and meat products, sauces, shredded cheeses, cookies, pastas, snacks, frozen desserts, and many other food products. This review emphasizes the health benefits of bamboo shoots and their potential for utilization as a health food.

Introduction

Bamboos, tall arborescent grasses, belonging to the family Poaceae, are popularly known for their industrial uses. They are plants of global interest because of their distinctive life form, ecological importance, and the wide range of uses and values they have for humans. Today, it helps more than 2 billion people meet their basic needs and as a widespread, renewable, productive, versatile, low- or no-cost, easily accessed, environment-enhancing resource; it has great potential to improve life, especially in the rural areas of the developing world (Sastry 2008). Bamboos are gaining increased attention as an alternative crop with multiple uses and benefits, providing human beings with various living resources. They are intermingled with the tradition and culture of rural and tribal populations and are an integral part of their cultural, social, and economic conditions (Tewari 1988; Madhab 2003) from times immemorial due to which they have been variously called as "The Cradle to Coffin Plant," "The Poor Man's Timber," "Friend of the People," "Green Gasoline," "The Plant with Thousand Faces," and "The Green Gold." This green gold is sufficiently cheap and plentiful to meet the vast needs of human populations from the "child's cradle to the dead man's bier." Because of its multifarious utility, both in the traditional way for the rural people as well as in modern society, bamboo is becoming a very important plant worldwide. There are more than 1500 different documented traditional uses of bamboo (INBAR 1997; Shrestha 1999). At present, there are about 3000 companies around the world engaged in the production of various bamboo-based products such as panels, flooring, pulp, charcoal, edible shoots, and other daily-use articles (Xuhe 2003). Bamboos provide food, shelter, medicine, raw materials for construction, wood substitute, and paper and pulp for industry. They are also used for making furniture, handicrafts, containers, tool handles, poles, musical instruments, bows and arrows, boats, rafts, fishing poles, and so on. The leaves have been used as fodder for livestock by the Japanese for hundreds of years. It is also a very important food for the giant pandas in China, because they survive only on bamboos. Many bamboos are popularly used as ornamental plants to beautify homes and gardens. In addition, due to their characteristic growth habits, particularly its interwoven system of rhizomes and roots that performs the function of cohesion, bamboos have enormous potential for alleviating many environmental conditions such as soil erosion control, water conservation, land rehabilitation, and carbon sequestration (Benzhi and others 2005).

Though more popularly known for industrial usage, a lesser known fact of bamboos is the utilization of its juvenile shoots as food. A traditional forest vegetable in China for more than 2500 y, bamboo shoots are not only delicious but are also rich in nutrients and rank among the 5 most popular healthcare foods in the world.

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Table 1–List of commercially important edible bamboos consumed in various countries.

S. Nr	Country	Species of bamboo shoots consumed	Reference
1.	Australia	*Bambusa oldhamii, Dendrocalamus asper, D. brandisii, D. latiflorus, B. arnhemica, Gigantochloa atter, Phyllostachys pubescens, P. heterocycla* var. *pubescens,*	Midmore and others (1998); Barnes and others (1999); Kleinhenz and others (2000)
2.	Bhutan	*Dendrocalamus giganteus, D. hamiltonii* var. *edulis, D. hookeri, D. sikkimensis*	Stapleton (1994)
3.	China	*Bambusa oldhamii, Dendrocalamus asper, D. brandisii, D. latiflorus, Phyllostachys praecox, P. iridescens, P. nuda Phyllostachys makinoi, P. pubescens, P. viridis, Pleioblastus amarus, Thyrsostachys siamensis.*	McClure (1935); Qiu (1992); Turtle (1995); Scurlock and others (2000); Lu and others (2009)
4.	India	*B. balcooa, B. bambos, B. kingiana, B. nana, B, nutans, B. pallida, B. polymorpha, B. tulda, B. vulgaris* var. *vulgaris, Chimonobambusa hookeriana, Dendrocalamus asper, D. giganteus, D. hamiltonii, D. hookerii, D. longispathus, D. membranaceus, D. sikkimensis, D. strictus, Gigantochloa rostrata, Melocanna baccifera, Phyllostachys bambusoides, Schizostachyum capitatum, Teinostachyum wightii, Thyrsostachys siamensis, T. oliveri, Schizostachyum dullooa,*	Tripathi (1998); Bhatt and others (2003, 2004); Bhatt and others (2004), Nirmala and others (2007); Jeyaram and others (2009, 2010)
5.	Japan	*Bambusa oldhamii, Dendrocalamus asper, Phyllostachys edulis, P. bambusoides, P. pubescens, P. mitis*	Scurlock and others (2000)
6.	Korea	*Phyllostachy pubescens, P. nigra, P. heterocycla*	Kim and others (2007)
7.	Nepal	*Dendrocalamus giganteus, D. hamiltonii, D. hookeri, D. sikkimensis*	Stapleton (1994)
8.	Puerto Rico	*Bambusa polymorpha, Guadua augustifolia, Dendrocalamus membranaceus, D. asper, Gigantochloa levis, Melocanna baccifera, Sinocalamus oldhami,*	Kennard and Freyre (1957)
9.	Taiwan	*Bambusa edulis, B. multiplex, B. oldhamii, B. pallida, Dendrocalamus asper, D. latiflorus, Phyllostachys makinoi, P. pubescens* and *Thyrsostachys siamensis*	ERG (2004)
10.	Thailand	*Bambusa edulis, B. oldhamii, B. pallida, Dendrocalamus asper, D. latiflorus, Thyrsostachys siamensis*	Scurlock and others (2000); ERG (2004)
11.	United States	*Phyllostachys dulcis, P. edulis, P. bambusoides, P. pubescens, P. nuda, P. viridis*	Young (1954); Rubatzky and Yamaguchi (1997); Diver (2001)

Bamboo shoots have a long history of being used as a source of both food and medicine in China and Southeast Asia (Bao 2006). In Japan, the bamboo shoot is called the "King of Forest Vegetables." In China, knowing the nutritional value and delicious taste, people considered bamboo shoots a treasure dish in the Tang Dynasty (618 to 907) and there was a saying that "there is no banquet without bamboo." The properties of bamboo shoots were recorded in the book Compendium of Materia Medica, a pharmaceutical text written during the Ming Dynasty (1368 to 1644), with the following words: "It's slightly cold, sweet, nontoxic, and it quenches thirst, benefits the liquid circulatory system and can be served as a daily dish" (Yuming and Jiru 1999). Presently, though the shoots are consumed more as a vegetable by local people, they are made available to others as a delicacy in up-scale markets and specialty restaurants. Hence, bamboos are no longer considered as "poor man's timber" but they form a "rich man's delicacy." Most bamboo species produce edible shoots but less than 100 species are commonly grown or utilized for their shoots (Midmore 1998; Collins and Keilar 2005). Major edible bamboo species consumed are listed in Table 1. The evergreen bamboo plant consists of aerial stems known as culms, which arise from a network of rhizomes and bear branches and leaves. A new emerging young culm is known as bamboo shoot or juvenile shoot. It is actually a culm that emerges from the ground in full diameter and contains nodes and internodes in a vertically miniaturized form. The young shoots are tightly clasped with overlapping sheaths that have to be removed to extract the edible part. New culms or juvenile shoots in bamboos usually develop with the beginning of the monsoon season during which the young edible shoots are harvested. The typical "shooting season" of a species rarely exceeds 2 mo. This period can be extended by modifying the cultivation and management practices. Fresh shoots have a crisp, crunchy taste, and sweet flavor, imparting a unique taste. They are mostly used in making appetizing soups, delicious snacks, hot curries, spicy stir-fries, attractive salads, pickles, aromatic fried rice, spring rolls, and other stewed and fried dishes. Shoots are also used as an extender, because the tissue takes on the flavor of the ingredients in which it is cooked. The most common preparation involves boiling the shoots in stocks, soups, or salted water for use in assorted dishes. The shoots are not only used as vegetables but are also processed and preserved in many forms such as dried, fermented, salted, pickled, water soaked, and canned. Bamboo shoots are gastronomic treats whether used fresh or in fermented or roasted form. In addition to being delicious, bamboo shoots are rich in some nutrient components, mainly proteins, carbohydrates, and minerals but have a low fat content. Bamboo shoots also contain phytosterols and a high amount of fiber that have cholesterol-lowering and anticarcinogenic activity and therefore could be called nutraceuticals or natural medicines. The shoots are free from residual toxicity as they grow without the application of hazardous fertilizers or pesticides.

Consumption of bamboo shoots is mainly concentrated in Southeast Asia, where they are a popular ingredient in the local cuisine. China has the largest bamboo industry producing approximately 1.3 million metric tons of fresh bamboo. Worldwide, more than 2 million tons of bamboo shoots are consumed annually of which about 1.3 million tons are produced in China alone (Xuhe 2003; Kleinhenz and others 2000). The popularity of Chinese restaurants worldwide gives an opportunity for people in many countries to taste this bamboo vegetable. In India, however, despite the fact that it is the 2nd largest producer of bamboos after China, not much importance has been given to the use of bamboo shoots as food due to lack of awareness of the edible characteristics of the shoots. Consumption of tender shoots is confined mainly to the Northeastern states of India where they are part of the traditional cuisine. Canned and preserved bamboo shoots currently dominate international trade, but due to increased consumer demand for nonprocessed food, it is projected that the share of fresh shoots will significantly increase in the near future. This review focuses on the nutritional value of bamboos, its impact on human health, and prospects of utilization as a health food.

Nutritional Value of Bamboo Shoots

The nutritional value of edible shoots of different bamboo species has been worked out by several workers (Giri and Janmejoy 1992; Shi and Yang 1992; Tripathi 1998; Chen and others 1999; Sharma and others 2004; Xu and others 2005; Kumbhare and Bhargava 2007; Nirmala and others 2007, 2008). Bamboo shoots are low in calories, high in dietary fiber, and rich in various nutrients. The main nutrients in bamboo shoots are protein, carbohydrates, amino acids, minerals, fat, sugar, fiber, and inorganic salts. The shoots have a good profile of minerals, consisting mainly of potassium (K), calcium (Ca), manganese, zinc, chromium, copper, iron (Fe), plus lower amounts of phosphorus (P), and selenium (Shi and Yang 1992; Nirmala and others 2007). Fresh shoots are a good source of thiamine, niacin, vitamin A, vitamin B6, and vitamin E (Visuphaka 1985; Xia 1989; Shi and Yang 1992). They are rich in protein, containing between 1.49 and 4.04 (average 2.65 g) per 100 g of fresh bamboo shoots. They contain 17 amino acids, 8 of which are essential for the human body (Qiu 1992; Ferreira and others 1995). Tyrosine amounts to 57% to 67% of the total amino acid content (Kozukue and others 1999). Fat content is comparatively low (0.26% to 0.94%) and the shoots contain important essential fatty acids. The total sugar content, 2.5% on average, is lower than that of other vegetables. The water content is 90% or more. Major advances have been made in fresh shoot production and processing and in the analysis of nutrient components of edible shoots. Based on nutritional analyses, it has been determined that bamboo shoots are a good source of food energy and are being projected as a new health food. This is because bamboo shoots are endowed with these health-enhancing properties.

(1) Rich in nutrients: Shoots have a high content of protein (amino acids), carbohydrate, minerals, and several vitamins.
(2) Function as nutraceuticals: Nutraceuticals are ordinary foods with components or ingredients imparting a specific medical or physiological benefit other than a purely nutritional effect. Bamboo shoots contain phytosterols and a high amount of fiber that can qualify as "nutraceuticals" or "natural medicines." Phytosterols have cholesterol-lowering activity (Brufau and others 2008).
(3) High fiber content, almost no calories: Bamboo shoots are a good source of edible fiber (6 to 8 g/100 g fresh weight), which helps in lowering the blood cholesterol. Dietary fibers are vegetable fibers obtained from fiber-rich parts of plants. They are neutral in taste and odor free and have no calories and fats. Bamboo fiber is available as a white powder with at least 95% fiber. A number of companies market such fiber additives that are rich sources of dietary fiber.
(4) Low fat: Fat content is extremely low in bamboo shoots (2.46 g/100 g) that are, therefore, very good for weight-conscious and dieting people.
(5) Appetizer: The high cellulosic content of bamboo shoots stimulates appetite. Being crisp, crunchy, and tender with a sweet flavor, shoots have a unique and delicious taste that function as an appetizer.

Fresh shoots of 14 species have been analyzed for their nutritive value (Table 2). As can be seen, the fresh shoots have a high content of carbohydrates, proteins, and fiber but are low in fat. Protein content is highest in *Dendrocalamus hamiltonii* (Nees and Arn. ex Munro) (3.72 g/100 g fresh weight). Carbohydrate content ranged from 4.32 to 6.92 g/100 g fresh weight with *Bambusa tulda* (Roxb.) having the highest. Fiber content was maximum in *B. kingiana* (Gamble) (4.49 g/100 g fresh weight). Shoots of *B. bambos* ([Linn.] Voss) and *B. tulda* (Roxb.) have sweet flavor, are tender, and tasty and are the most popular, being liked by all consumers. Of the 14, 5 species, *B. tulda*, *B. bambos*, *D. asper* ([Schultes f.] Becker ex Heyne), *D. giganteus* (Munro), and *D. hamiltonii* are nutritionally better than the rest and have high potential for the necessary massive commercial production of shoots. Our studies indicate that there is an overall decrease in all the nutrient components in 10-d-old shoots compared to the freshly emerging juvenile shoots (Nirmala and others 2007). Freshly emerged shoots are nutritionally richer than the fermented and canned shoots. A comparison of the nutrient components of juvenile bamboo shoots with some of the commonly consumed vegetables revealed that free amino acid, protein, and dietary fiber contents in bamboo shoots was higher than all other vegetables listed in Table 3. Except for *D. brandisii*, all the presently studied bamboos have higher protein and fiber contents than the common vegetables. Bamboo shoots, though having lower vitamin E content, have a higher amount of vitamin C in comparison to the other green vegetables except Brassica. However, relative nutrient density on dry weight basis needs to be worked out.

Regarding minerals, bamboo shoots have a comparatively higher K content than most of the vegetables except spinach, *Spinacea oleracea* (Linnaeus) (558 mg/100 g) and potatoes, *Solanum tuberosum* (Linnaeus) (421 mg/100 g). The sodium (Na) contents in cucumber, *Cucumis sativa* (Linnaeus), *S. tuberosum*, brinjal, *S. melongena* (Linnaeus), and ladies finger, *Abelmoschus esculantus* [(Linnaeus) Moench.] are lower than that of bamboo shoots (Table 4). Magnesium (Mg) is a life-supporting element and has an indispensable role in body metabolism. Its content was highest in the shoots of *D. giganteus* (10.09 mg/100 g) that is close to that of *S. melongena* (10.0 mg/100 g fresh weight). Children and women before menopause, during pregnancy or while nursing, require high amounts of Fe (Tapiero and others 2001). This can be obtained by consumption of bamboo shoots that contain a comparatively higher amount of Fe than other commonly consumed vegetables.

Table 2–Macronutrients (g/100 g fresh weight), vitamin C, vitamin E (mg/100 g fresh weight), moisture, dietary fiber, and ash content in the freshly emerged juvenile shoots of various species.

Name of species	Amino acids	Proteins	Carbohydrates	Starch	Fat	Vitamin C	Vitamin E	Ash	Moisture	Dietary fiber
B. bambos	3.98 ± 0.02	3.57 ± 0.03	5.42 ± 0.02	0.25 ± 0.04	0.50 ± 0.02	1.90 ± 0.08	0.61 ± 0.05	1.38 ± 0.03	89.83 ± 0.08	3.54 ± 0.02
B. kingiana	3.701 ± 095	3.57 ± 0.08	5.45 ± 0.12	0.34 ± 0.03	0.35 ± 0.03	2.10 ± 0.12	0.50 ± 0.10	1.38 ± 0.23	90.00 ± 1.02	4.490 ± 0.06
B. nutans	3.89 ± 0.04	2.84 ± 0.12	5.47 ± 0.05	0.21 ± 0.02	0.40 ± 0.02	1.19 ± 0.10	0.47 ± 0.06	0.68 ± 0.11	92.00 ± 0.23	2.28 ± 0.01
B. polymorpha	3.42 ± 0.02	3.64 ± 0.02	5.44 ± 0.05	0.38 ± 0.04	0.46 ± 0.03	2.60 ± 0.13	0.49 ± 0.12	0.76 ± 0.22	90.26 ± 1.68	3.815 ± 0.06
B. tulda	3.65 ± 0.03	3.69 ± 0.03	6.92 ± 0.04	0.59 ± 0.12	0.48 ± 0.07	1.42 ± 0.06	0.61 ± 0.14	0.85 ± 0.13	83.60 ± 1.26	3.97 ± 0.02
B. vulgaris	3.57 ± 0.04	3.64 ± 0.03	6.51 ± 0.05	0.27 ± 0.05	0.50 ± 0.01	4.80 ± 0.11	0.52 ± 0.10	1.01 ± 0.21	90.60 ± 0.82	4.24 ± 0.01
D. asper	3.12 ± 0.07	3.59 ± 0.06	4.90 ± 0.11	0.36 ± 0.08	0.40 ± 0.06	3.20 ± 0.06	0.91 ± 0.13	0.95 ± 0.03	89.40 ± 0.98	3.54 ± 0.07
D. brandisii	3.01 ± 0.11	2.31 ± 0.12	4.90 ± 0.10	0.49 ± 0.04	0.24 ± 0.10	1.59 ± 0.10	0.42 ± 0.10	0.61 ± 0.11	89.80 ± 0.15	4.03 ± 0.09
D. giganteus	3.86 ± 0.13	3.11 ± 0.17	5.10 ± 0.04	0.51 ± 0.06	0.39 ± 0.03	3.28 ± 0.02	0.69 ± 0.03	0.89 ± 0.13	90.70 ± 0.12	2.65 ± 0.03
D. hamiltonii	3.18 ± 0.05	3.72 ± 0.12	5.50 ± 0.08	0.47 ± 0.03	0.41 ± 0.02	2.45 ± 0.08	0.71 ± 0.03	0.86 ± 0.20	92.51 ± 0.51	3.90 ± 0.03
D.membranaceus	3.46 ± 0.02	3.38 ± 0.10	5.40 ± 0.03	0.23 ± 0.04	0.43 ± 0.05	1.58 ± 0.06	0.65 ± 0.10	0.63 ± 0.04	89.30 ± 1.34	2.91 ± 0.06
D. strictus	3.07 ± 0.03	2.60 ± 0.07	6.17 ± 0.02	0.31 ± 0.05	0.33 ± 0.04	2.43 ± 0.11	0.58 ± 0.03	0.71 ± 0.10	90.10 ± 0.93	2.26 ± 0.01
G. albociliata	3.52 ± 0.11	3.05 ± 0.11	4.59 ± 0.09	0.31 ± 0.04	0.51 ± 0.10	1.00 ± 0.08	0.60 ± 0.04	0.73 ± 0.04	89.23 ± 0.30	4.15 ± 0.11
G. rostrata	3.17 ± 0.08	3.56 ± 0.11	4.32 ± 0.11	0.22 ± 0.03	0.56 ± 0.12	3.20 ± 0.10	0.49 ± 0.05	0.68 ± 0.05	90.56 ± 1.02	4.20 ± 0.09

B = Bambusa; D = Dendrocalamus; G = Gigantochloa.
± indicates standard deviation.

Table 3–Comparative account of various nutrients (g/100 g) present in freshly emerged juvenile bamboo shoots and some common vegetables.*

Species	Amino acids	Proteins	Carbohydrates	Starch	Fat	Vitamin C (mg/100 g)	Vitamin E (mg/100 g)	Dietary fiber	Ash	Moisture
Bambusa tulda	3.65	3.69	6.92	0.59	0.48	1.42	0.61	3.97	0.85	83.60
Dendrocalamus hamiltonii	3.18	3.72	5.5	0.50	0.41	2.45	0.71	3.90	0.86	92.51
WINTER VEGETABLES										
Amaranthus gangeticus (Amaranth)	1.3	4.0	6.1	–	0.5	1.0	43.3	1.0	1.5	85.7
Brassica oleracea var. *botrytis* (Cauliflower)	0.4	5.9	7.6	–	0.4	2.5	46.4	2.0	1.0	90.8
Brassica oleracea var. *capitata* (Cabbage)	0.3	1.8	5.6	–	0.1	2.6	32.2	1.0	0.7	91.9
Daucus carota (Carrot)	0.2	0.9	10.6	–	0.2	1.2	3.0	1.2	1.1	86.0
Raphanus sativus (Radish)	0.1	0.7	3.4	–	0.1	1.6	15.0	0.6	0.6	94.4
Spinacea oleracea (Spinach)	0.3	2.0	2.9	–	0.7	0.6	28.1	2.0	1.7	92.1
Solanum tuberosum (Potato)	0.2	1.6	22.6	15.4	0.1	0.4	19.7	0.4	1.1	74.7
SUMMER VEGETABLES										
Abelmoschus esculantus (Ladies finger)	0.3	1.9	6.4	–	0.2	1.2	13.0	1.2	1.1	88.3
Citrullus vulgaris (Tibda)	0.2	1.4	3.4	–	0.2	1.0	–	1.0	–	93.5
Cucumis sativus (Cucumber)	0.1	0.6	2.5	0.1	0.1	0.7	3.2	0.4	0.4	96.3
Cucurbita maxima (Pumpkin)	0.2	1.4	6.5	–	0.4	0.7	9.0	1.1	0.8	92.6
Lagenaria siceraria (Bottle gourd/Lauki)	0.4	0.6	3.4	–	0.1	0.6	12.0	0.6	0.4	92.4
Luffa acutangula (Tori)	0.1	1.2	3.4	–	0.1	0.5	5.0	3.3	0.6	95.2
Phaseolus vulgaris (French bean)	0.3	18.8	20.1	–	2.0	4.6	–	1.8	4.3	10.8
Solanum melongena (Brinjal)	0.2	1.4	4.0	–	0.3	1.3	12.0	1.3	0.8	92.7

*Data taken from Gopalan and others (1971), Cantwell and others (1996), and USDA National Nutrient Database (2006).
– = valid authentic data not available.

Table 4–Comparative account of various mineral elements (mg/100 g) present in the freshly emerged juvenile bamboo shoots and some common vegetables.*

Species	Ca	Cu	Fe	Mg	Mn	K	P	Se	Na	Zn
Bambusa tulda	4.06	0.44	3.19	8.68	0.70	408	19.31	0.4μg	12.96	0.72
Dendrocalamus hamiltonii	3.00	0.29	2.69	6.09	0.16	416	28.12	0.8μg	9.32	0.70
WINTER VEGETABLES										
Amaranthus gangeticus (Amaranth)	397.0	0.08	1.8	55.0	0.36	341	247	0.9μg	20.0	0.18
Brassica oleracea var. *botrytis* (Cauliflower)	33.0	0.13	1.23	15.0	0.20	303	57.0	0.6μg	30.0	0.40
Brassica oleracea var. *capitata* (Cabbage)	47.0	0.02	0.6	15.0	0.18	246	23.0	0.9μg	18.0	0.30
Daucus carota (Carrot)	80.0	0.10	1.03	18.0	0.16	108	530	1.2μg	35.6	0.36
Raphanus sativus (Radish)	35.0	0.02	1.0	10.0	0.22	393	20.0	0.6μg	39.0	0.30
Spinacea oleracea (Spinach)	99.0	0.10	2.70	79.0	0.90	558	49.0	0.1μg	79.0	0.50
Solanum tuberosum (Potato)	12.0	0.16	0.80	23.0	0.20	421	58.0	0.3μg	11.0	0.30
SUMMER VEGETABLES										
Abelmoschus esculantus (Ladies finger)	66.0	0.11	0.35	11.0	0.19	103	56.0	–	6.9	0.42
Citrullus vulgaris (Tinda)	–	0.12	0.9	–	–	24	–	–	35.0	
Cucumis sativus (Cucumber)	14.0	0.09	0.9	12.0	0.14	136	25.0	0.1μg	2.0	0.23
Cucurbita maxima (Pumpkin)	21.0	0.10	0.8	12.0	0.10	340	44.0	0.3μg	5.6	0.30
Lagenaria siceraria (Bottle gourd/Lauki)	26.0	0.03	0.7	11.0	0.1	150	13.0	0.2μg	2.0	0.70
Luffa acutangula (Tori)	18.0	0.08	0.46	14.0	0.07	160	26.0	–	2.9	0.2
Phaseolus vulgaris (French bean)	186.0	0.4	3.4	188.0	1.20	1316	304	12.9μg	18.0	1.9
Solanum melongena (Brinjal)	18.0	0.12	0.90	10.0	0.13	200	47.0	0.02μg	3.0	0.22

* Data taken from Gopalan and others (1971), Cantwell and others (1996), and USDA National Nutrient Database (2006).
– = valid authentic data not available.

A higher amount of selenium, commonly known as "Miracle life element," is present in the bamboo shoots of some species compared to other vegetables.

Changes in Nutrient Components of Shoots during Processing and Aging

There are numerous ways in which bamboo shoots are processed and prepared. The major processing methods are shown in Figure 1. During processing, the accompanying physical and chemical changes alter the nutritional integrity of the shoots. Changes in nutrient components in shoots after boiling, fermentation, canning, and during aging have been studied (Kumbhare and Bhargava 2007; Nirmala and others 2007, 2008). Protein and sugar contents in the shoots decrease after boiling. The ash content also decreases on boiling, fermentation, and canning. The reduction varies from 20% after boiling, 15% after canning, and 12% after fermentation. The carbohydrate content ranges from 4.09 to 6.91 g/100 g fresh weight, and though there was an increase in the content after boiling, there was a substantial increase up to 72% after fermentation and canning (Nirmala and others 2008). The fiber content does not seem to change after boiling (Kumbhare and Bhargava 2007) but it increases significantly after fermentation and canning (Nirmala and others 2008). Changes in the nutrient components in fresh, fermented, and canned shoots of a commercially important bamboo, *D. giganteus*, were determined by Nirmala and others (2008). The study revealed that the freshly harvested shoots are richer in nutrient components compared to canned and fermented shoots. There was an overall decrease of the nutrient components, except the dietary fiber content, during fermentation and canning. Fresh shoots have higher quantities of macronutrients such as amino acids, proteins, carbohydrates, fat, and fiber than the fermented and canned shoots, except for vitamins C and E and minerals such as Ca, Fe, K, and P. Vitamin C and E content were highest in raw shoots (3.28 mg and 0.69 mg/100 g fresh weight) followed by canned (1.8 mg and 0.3 mg/100 g fresh weight) and fermented shoots (1.09 mg and 0.21 mg/100 g fresh weight). The moisture content was highest in the canned shoots. Thus, freshly harvested shoots, being nutritionally richer than the fermented shoots are recommended for consumption as food. Changes in nutrient components were also observed during

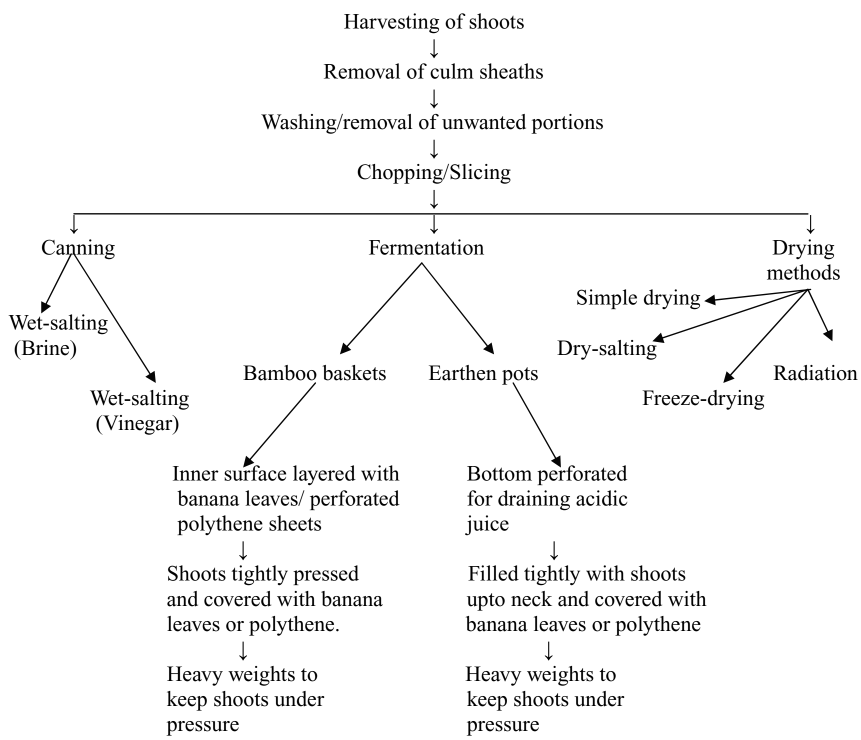


Figure 1–Processing and preservation techniques for bamboo shoots.

the aging and harvesting time of emerging juvenile shoots (Hu 1985; Hu and others, 1986; Nirmala and others 2007). A study conducted on 5 commercially important bamboos, *B. bambos*, *B. tulda*, *D. asper*, *D. giganteus*, and *D. hamiltonii*, showed that whereas nutrient components of the shoots were depleted with aging, the dietary fiber, and moisture contents increased. Vitamin and mineral contents also decrease in the older shoots. This indicates that freshly emerging shoots are nutritionally superior to the older emerged shoots.

Bamboo Shoots and Human Health

Bamboo shoots have been regarded as a traditional Chinese medicinal material for more than 2000 y, and according to archaic Chinese medicinal books, such as "Ben Chao Qui Zheng," "Ben Jing Feng Yuan," "Yao Pin Hua Yi," and "Jing Yue," were proclaimed to be beneficial to human health, by promoting motion and peristalsis of the intestine, helping digestion, and preventing and curing cardiovascular diseases (CVDs) and cancers. In South Asian countries, bamboos have been utilized for traditional medicine treatments to relieve hypertension, sweating, and paralysis. However, little scientific evidence has supported such claims until now. Modern research has revealed that bamboo shoots have a number of health benefits, from cancer prevention and weight loss to lowering cholesterol level, improving appetite and digestion (Table 5). It is also low in sugar and therefore can be used by persons on sugar-restricted diets. The shoots also contain anticarcinogenic agents, and making them a regular part of a diet effectively reduces the free radicals that can produce harmful carcinogens. It is believed that bamboo extract may have antioxidant activities and provide antiinflammatory effects (Hu and others 2000; Lu and others 2005). Furthermore, bamboo-derived pyrolysates have been proposed to have antimicrobial and antifungal activities (Fujimura and others 2005) and to protect neurons from oxidative stress (Akao and others 2004). Hong and others (2010) studied the effects of pyrolysates-derived from 3 bamboo species, *Phyllostachys bambusoides* (Siebold et Zucc.), *P. nigra* ([Lodd. ex Lindl.] Munro), and *P. pubescens* (Mazel ex J. Houz.), and indicated that pyrolysates may have antiapoptotic effects and can be useful as a supplement for ischemic injury treatment. Several antimicrobials and antioxidants have been isolated by supercritical CO_2 and subsequent hydrothermal treatment of the residues from moso bamboo, including an ethoxyquin, a sesquiterpene, and a cyclohexanone derivative (Quitain and others 2004). Bamboo shoots are also reported to have anticancer, antibacterial, and antiviral activity due to the presence of lignans that are an important component of fiber (Shi and Yang 1992; Fujimura and others 2005). Because of its high content of K, bamboo helps to maintain normal blood pressure and is labeled as a heart-protective vegetable. Its relatively high content of up to 4% cellulose increases

Table 5–Bamboo shoots and its beneficial effects on human health.

S. Nr.	Potential activities on human health	Reference
1.	Antioxidant and antiinflammatory effects of bamboo shoot extracts	Hu and others (2000); Lu and others (2005)
2.	Antimicrobial and antifungal activities of bamboo shoot pyrolysates	Fujimura and others (2005)
3.	Protect neurons from oxidative stress	Akao and others (2004)
4.	Antiapoptotic activities of bamboo shoot-derived pyrolysates and as a supplement for ischemic injury treatment	Hong and others (2010)
5.	Anticancer, antibacterial, antiviral activity of bamboo shoot fiber	Shi and Yang (1992); Fujimura and others (2005)
6.	Antifatigue activity	Zhang and others (2006)
7.	Cholesterol lowering properties	Park and Jhon (2009)

the peristaltic movement of the intestines and helps digestion. It also prevents constipation and decreases body fat.

Macronutrients

Bamboo shoots are low in calories, one cup of half-inch long slices containing a mere 14 to 15 g of fat. The macronutrients present in the shoots include amino acids, proteins, carbohydrates, fiber, and fat. Some of the nutrient components in bamboo shoots are higher than those contained in commonly consumed vegetables (Table 3).

Protein

Protein is an indispensible requirement for the growth and maintenance of all biological organisms. Every cell in our body needs protein to carry out the metabolic actions that sustain us. The amount of protein required for normal health is variable depending on many factors, mainly body weight, age, physical activity, health condition, environment, among others. Growing children and pregnant and lactating women, however, require more protein per unit weight than adults in normal conditions. Bamboo shoots are rich in protein containing between 1.49 and 4.04 g (average 2.65 g) per 100 g of fresh bamboo shoots. In our studies of 14 bamboo species, the protein content in the juvenile shoots ranged from 2.31 to 3.72 g/100 g fresh weight, the highest being in *D. hamiltonii* followed by *B. bambos*. Similar values were also reported by other workers (Sundriyal and Sundriyal 2001; Bhatt and others 2005). Shoots contain 17 amino acids, 8 of which, serine, methionine, isoleucine, leucine, phenyalanine, lysine, and histidine are essential for the human body (Qiu 1992). Lysine is beneficial for a child's growth and development, and it is lacking in cereals. The recommended dietary allowance for protein is 0.8 g/kg of body weight for adults. In general, 1 g protein provides 4.2 kcal of energy to the body. If the diet does not contain sufficient amounts of carbohydrate and fat, then dietary protein may be broken down to provide energy. Since bamboo shoots have an average protein content of 2.65 g/100 g fresh weight, consuming the shoots will supply a generous amount of protein to the body.

Fiber

Consumer interest in wholesome/nutritious foods and beverages continues, and one category with potential for fast growth is foodstuffs fortified with fiber. Previously referred to as roughage, bulk, or ballast, fiber is now termed dietary fiber and has assumed immense importance in health education. Dietary fiber includes cellulose and lignin, hemicelluloses, pectins, gums, and other polysaccharides and oligoscacharides associated with plants (Chawla and Patil 2010) and has been associated with a number of health benefits, such as including a faster "transit time," the time it takes for the body's waste to be moved out of the body, reduced exposure of the body to carcinogens or cancer-causing components in food and fluids, bowel protection, and an increase in the amount of butyrate, the preferred energy source for cells called colonocytes. An increase in dietary fiber reduces the blood pressure (Anderson and Strong 1983). According to George and others (1982), dietary fiber is useful in the management of hypertension and obesity through its effect on energy density of food and the extent of interference with the nutrients of bioavailability.

Intake of fiber through various foods such as nuts, whole grain flour, and fruits and vegetables is now associated with decreased low-density lipoprotein (LDL) cholesterol, lower insulin demand, keeping the digestive tract healthy, increased stool bulk, softening of fecal mass, improved laxative properties, and body weight regulation (Gordon 1989; Brown and others 1999; Howarth and others 2001; Park and others 2005). The recommended level of fiber for adults is 25 to 30 g a day, in combination with at least 2 L of fluid to ensure thorough digestion. Extracts rich in dietary fiber obtained from plants could be used as functional ingredients as they improve not only digestive health, but weight management, cardiovascular health, and general wellness. The role of fiber in preventing CVDs has been well documented (Viuda-Martos and others 2010). The beneficial effects of high-fiber diets in protecting against CVD are not limited to their effects on the risk of developing type 2 diabetes or their contribution to weight loss. Evidence suggests that increased consumption of insoluble as well as soluble dietary fibers can directly impact the risk of developing CVDs by targeting risk factors such as elevated serum LDL cholesterol levels (Chau and others 2004; Kendall and others 2009). High cholesterol levels, or hypercholesterolemia, are a major risk factor for CVD, which causes almost 50% of deaths in Europe and is reported to cost the EU economy an estimated €169bn ($202bn) per year. According to the American Heart Association, 34.2% of Americans (70.1 million people) suffered from some form of CVD in 2002.

Bamboo shoots are a rich source of dietary fiber (Nirmala and others 2009). They have high amounts of fiber, ranging from 2.23 to 4.20 g/100 g fresh weight of shoot in some bamboo species. As a dietary fiber source, the shoots have beneficial effects on lipid profile and bowel function. Studies conducted by Park and Jhon (2009) have confirmed the beneficial effects of consuming a high-fiber diet containing bamboo shoots in lowering blood cholesterol levels and improving bowel functions in healthy young women. Supplementing the diet with bamboo shoots was associated with reductions in total and LDL cholesterol levels in 8 young women. Park and Jhon (2009) had recruited 8 women with an average age of 22 and an average body mass index (BMI) of 20.2, and randomly assigned them to receive a dietary fiber-free diet (control), a diet containing 25 g of cellulose, or a diet containing 360 g of bamboo shoots. Each dietary intervention lasted 6 d and the women underwent each segment. At the end of the study, the bamboo shoot-rich diet was associated with a 15.7 and 11.8 mg/dL reduction in total cholesterol levels, compared to the control and cellulose diets, respectively. Moreover, LDL cholesterol was reduced by 16.1 mg/dL following the bamboo shoot diet compared to the control diet, but there were no differences between the bamboo group and the cellulose group. High-density lipoprotein (HDL) cholesterol levels were unchanged by the bamboo diet but increased by 7.2 mg/dL following consumption of the cellulose diet. Following the bamboo shoot diet, the average number of bowel movements was 6.2 per day, compared to 4.3 and 5.6 in the control and cellulose groups, respectively. These results suggested that consumption of bamboo shoots, which contained high levels of dietary fiber, might help in preventing or delaying the onset of chronic diseases. Bamboo shoots are reported to have anticancer, antibacterial, and antiviral activity due to the presence of lignans, which is an important component of fiber (Shi and Yang 1992; Akao and others 2004). Chen and others (1985) reported a high content of hemicelluloses in 10 bamboo species that exists in the form of polyxylose. When hydrolyzed, polyxylose forms xylose that is hydrogenated to produce xylitol, a product extensively used in the food and chemical industries. Xylose is characterized by a special flavor and can relieve cough. Eating cooked bamboo shoots is also popularly claimed to make skin fair and smooth (Shi and Yang 1992).

Although fiber itself is invisible in food products, it is becoming one of the most appreciated ingredients in today's diet. In 2007,

Table 6–Application of bamboo fiber in the food industry.

Food items	Benefit
1. Bakery products Fragile dry bakery products such as pretzels, ice cream cones and cookies, cakes, wafers, baked, and fried tortilla chips. Noncaloric health bars.	Improves dough yield and consistency due to water binding capacity. Decrease of product breakage or crumbling; controls moisture loss in high- and intermediate-moisture foods. Fiber enrichment with noncaloric fiber in health nutrition bars.
2. Dairy products Milk, yogurt, ice cream, shredded cheeses.	Noncaloric fiber enrichment. Viscosity and consistency improvement, stabilizer. Creamy mouthfeel.
3. Meat and aquatic products	Excellent water retention capacity. Texture improvement and binding. Longer freshness and less fat absorption in product during processing.
4. Health beverages	Noncaloric fiber enrichment. Viscosity and consistency improvement, stabilizer creamy mouthfeel.
5. Miscellanous Sauces, dressings, juices, ketchup, mustard, low-calorie dressings, pasta.	Noncaloric fiber enrichment. Viscosity and consistency improvement, stabilizer creamy mouthfeel.

consumers ranked fiber number 5 among the top 10 functional foods (Sloan 2008). Fiber occurs in grains, fruits, vegetables, and beans, but only in minuscule amounts. Since bamboo fiber is a cheap alternative compared to fiber derived from wheat, oat, corn, potato, pea, soybean, and apples, several companies use it in their products. Bamboo fiber is now a common ingredient in breakfast cereals, pasta, shredded cheese, sauces, mustard, ketchup, beverages, fruit juices, snacks, frozen desserts, and bakery products (Table 6). It not only adds negligible calories to a product; it also improves texture in the products. Bamboo fiber is useful in powdered mixes, where anticaking properties and extra fiber are needed. It binds 3 to 5 times its weight in water, thus also helping to address moisture migration issues. The product can replace silicon dioxide in order to achieve an all-natural label. Spices and essences also "bind" to the fiber, which prolongs product shelf life. The fiber product is easily dispersed in water and has high absorption capacity through physical binding of liquids. Although fiber increases viscosity in beverages, it requires another agent to remain suspended. Custom grades and blends also are available for special applications. The powder is less dusty than other fiber powders and is easy to store and handle. Bamboo fiber when used as an ingredient improved the quality of cookies (Farris and Piergiovanni 2008). "Ameretti" is a unique Italian cookie that has a soft moist internal almond-paste, which contrasts with the thin, hard dry external crust. These cookies have a shelf life of about 7 d due to the quick hardening of the internal moist paste that decreases its quality and uniqueness and thus, its export value. Use of bamboo fiber as an ingredient is effective for preserving the softness of the internal paste for more than 10 d. Thus, addition of bamboo fiber as an ingredient could help control moisture loss in high- and intermediate-moisture foods.

Many companies use bamboo fiber in their products. Vitacel, a bamboo fiber product produced by J. Rettenmaier & Sohne, is used in fruit juices, beverages, spices, tablets, bakery goods, pasta, fragile products, batters, shredded cheese, sauces, mustard, and ketchup. CFF GmbH (Cellulose Fiber Fabric), based in Gehren, Germany, has developed a new type of fiber derived from the fiber-rich parts of bamboos. It consists of more than 90% water-insoluble fiber that cannot be broken down by the human digestive system; it bulks in the stomach, removes undesired metabolic by-products, and shortens intestinal transit time. InterFiber (Zhejiang, China), a Chinese company, is a producer and supplier of high quality, insoluble dietary fiber derived from natural plant sources such as wheat, bamboo, and cellulose.

Minerals

Juvenile bamboo shoots have a high content of minerals such as K, P, Na, Mg, Ca, and Fe. The shoots are labeled as a heart-protective vegetable because of its high content of K that helps to maintain normal blood pressure and a steady heart beat. Potassium, an essential macroelement is a heart-friendly mineral that helps to maintain normal blood pressure and a steady heart beat. The K content in bamboo shoots ranges from 232 to 576 mg/100 g fresh weight. People prone to high blood pressure are often advised to increase K intake and decrease Na consumption. The daily recommended intake of K is 2.0 to 5.5 g/d (Belitz and Grosch 1999). Trace elements present in bamboo shoots include cadmium, cobalt, copper, nickel, manganese, selenium, and zinc. These minerals are required by the human body for many metabolic activities. Selenium is incorporated into proteins to make selenoproteins that are important antioxidant enzymes. The antioxidant properties of selenoproteins help prevent cellular damage from free radicals, which are natural by-products of oxygen metabolism.

Bioactive Compounds

Increasing scientific evidence has indicated that consumption of certain foods may lead to reduce risk of certain diseases such as CVD, cancer, and other age-related conditions. Many investigations have led to the identification of certain food constituents belonging to the group "bioactive compounds" that can influence metabolism, gene expression, cellular signaling, and interact with disease precursors and disease-developing mechanisms (Rostagno and others 2010). Bioactive compounds are essential and nonessential compounds that occur in nature, are part of the food chain, and have an effect on human health (Kris-Etherton and others 2004; Biesalski and others 2009). Plant food contains many bioactive compounds in addition to those that are traditionally considered nutrients. These physiologically active compounds, referred to as "phytochemicals," are produced via secondary metabolism in relatively small amounts (Rodriguez and others 2006). They are being intensively studied to evaluate their effects on health. Some groups of phytochemicals that have significant health potentials are carotenoids, phenolic compounds (flavonoids, phytoestrogens, phenolic acids), phytosterols and phytostanols, saponins, tocotrienols, organosulfur compounds (allium compounds and glucosinolates), and nondigestible carbohydrates (dietary fiber and prebiotics). These compounds vary widely in chemical structure and function and are grouped accordingly. Because of the many plant-based bioactive compounds that have been identified, there have been numerous epidemiological, clinical, and experimental studies conducted to evaluate their health effects. Phenolic compounds, including their subcategory flavonoids, are present in all plants and have antioxidant properties. Plant sterol or phytosterol is a bioactive compound of all vegetable foods. Bamboo shoots are rich in both phenols and phytosterols.

Phytosterols

Much work has been focused on the nutritional benefits of bamboo shoots, mainly on insoluble and/or water-soluble components such as dietary fiber, proteins, amino acids, and vitamins, but quantitative data on lipid-soluble components, especially sterols are limited. Bamboo shoots, both fresh and fermented, are a good source of phytosterols that are the precursors of many pharmaceutically active steroids found in plants (Srivastava 1990; Sarangthem and Singh 2003a) and act as nutraceuticals (Miettinen 2003). Phytosterols or plant sterols are bioactive components occurring in all vegetable foods and represent the major part of the nonsaponifiable fraction of lipids that have many implications on human health (Normen and others 2002; Kritchevsky and Chen 2005; Phillips and others 2005; Lagarda and others 2006; Ostlund 2007). These compounds are 28- or 29-carbon alcohols and resemble cholesterol in vertebrates in terms of both function and structure. They form a group of triterpenes with a tetracyclic cyclopenta(a)phenanthrene structure and a side chain at carbon 17. The 4 rings (A, B, C, and D) have trans ring junctions, and 2 methyl groups are attached at C-18 and C-19. The basic sterol from which other sterol structures are derived is 5α-cholesten-3β-ol. Their properties for reducing serum LDL cholesterol level and thus in protecting against CVDs as well as other beneficial health effects have been known for many years according to Quilez and others (2003). Phytosterols are absorbed only in trace amounts but inhibit the absorption of intestinal cholesterol including recirculating endogenous biliary cholesterol, a key step in cholesterol elimination. In addition to their cholesterol lowering activity, experiments have suggested that phytosterols possess anticancer effects (Awad and Fink 2000; Choi and others 2007; Bradford and Awad 2008; Woyengo and others 2009), against cancer of the lungs (Mendilaharsu and others 1998), stomach (De Stefani and others 2000), ovaries (McCann and others 2003), and estrogen-dependent human breast cancer (Ju and others 2004). Phytosterols also inhibit the production of carcinogens, cancer cell growth, invasion and metastasis, and promote apoptosis in cancer cells (Meric and others 2006). Phytosterols affect host systems potentially enabling more antitumor responses, including boosting of immune recognition of cancer, influencing hormone-dependent growth of endocrine tumors, and altering sterol biosynthesis. They directly inhibit tumor growth by slowing cell cycle progression and inducing apoptosis. An antitumor agent has been prepared from moso bamboo (*P. pubescens*) that has an antitumor effect (Hiromichi 2007). Phytosterols also lower serum cholesterol levels as they inhibit the absorption of dietary cholesterol and rate of cholesterol esterification in the intestinal mucosa. In plants, more than 200 different types of phytosterols have been reported, the most abundant being B-sitosterol, campesterol, stigmasterol, and avenosterol (Jones 1999; Law 2000; Katan and others 2003; St-Onge and Jones 2003; Abumweis and Jones 2008). Of these, sitosterol is the most abundant phytosterol followed by campesterol (Ostlund 2002; Ryan and others 2007). Rich sources of phytosterols include grain legumes such as sesame, chickpeas, lentils, and peas; cereal grains such as wheat, corn, millet, rye, and barley (Ryan and others 2007); vegetable oils including corn oil (Ostlund 2007); and nuts such as pecans, pinenuts, pistachio nuts, peanuts, cashew nuts, and almonds (Ryan and others 2006), and bamboo shoots (He and Lachance 1998; Lachance and He 1998; Sarangthem and Singh 2003c; Lu and others 2010). Sterols cannot be synthesized by humans and are absorbed from the diet in small but significant amounts. Three predominant phytosterols have been identified in bamboos, β-sitosterol, campesterol, and stigmasterol, but some minor sterols have also been reported (Figure 2). Comprehensive and accurate data on the sterol content in the shoots of various bamboo species are not available.

Phytosterols have received particular attention because of their capability to lower serum cholesterol levels in humans (Marangoni and Poli 2010), resulting in significantly reduced risk of heart disease. Predominant sterols in bamboo shoots have been identified as β-sitosterol, campesterol, and stigmasterol (He and Lachance 1998; Lachance and He 1998). The phytosterol content and composition in shoots of 4 bamboo species, *Pleioblastus amarus*, *P.*

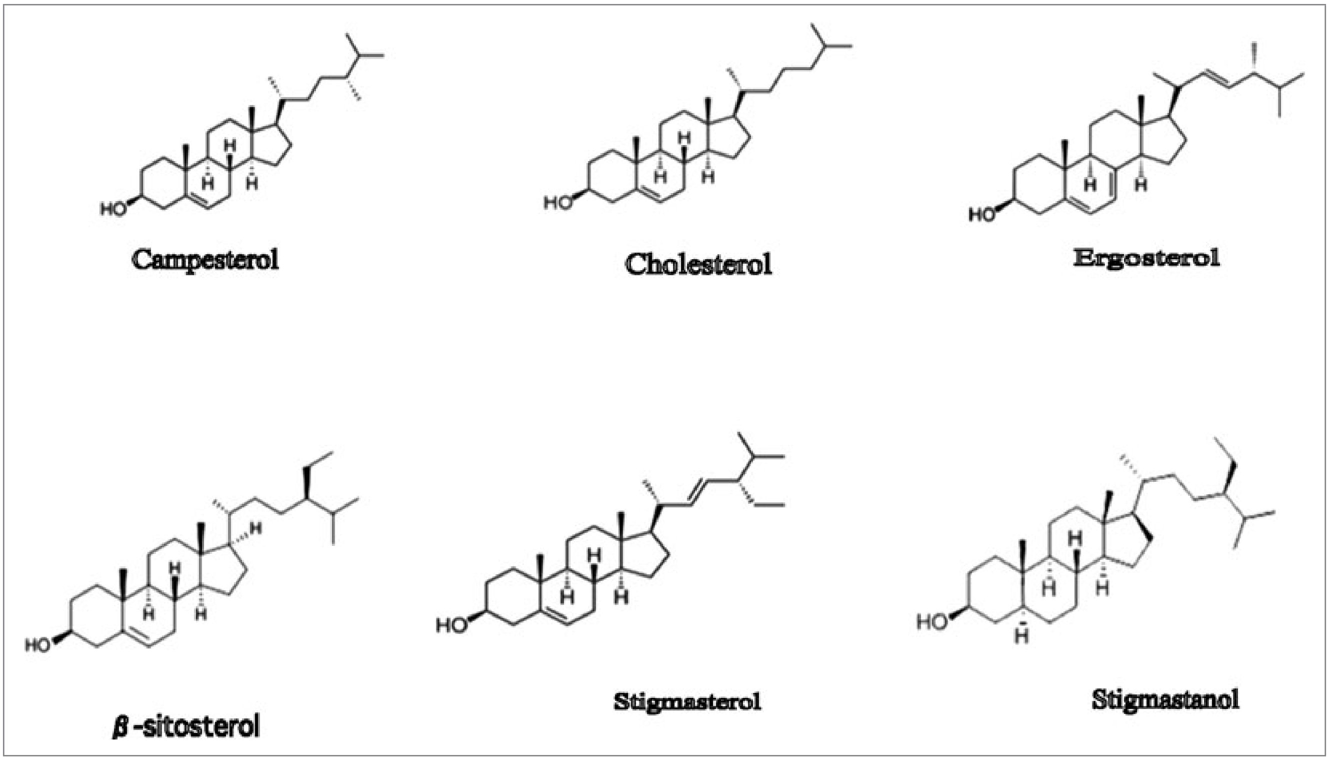


Figure 2–Phytosterols present in bamboo shoots and their corresponding structures.

pubescens, *D. latiflorus*, and *P. praecox*, were evaluated using ultra-performance liquid chromatography with atmospheric pressure chemical ionization mass spectrometry (MS) in order to facilitate dietary recommendations and comprehensive utilization of the shoots (Lu and others 2009). The major sterols present were β-sitosterol (24.6%), campesterol (2.2%), stigmasterol (1.2%), ergosterol (0.2%), cholesterol (0.6%), and stigmastanol (<0.1%); total phytosterol content was 28.7% (Lu and others 2010). Bamboo shoot oil (BSO) is a phytosterols-rich extract from the bamboo (*P. pubescens*) shoots obtained by supercritical carbon dioxide extraction and its protective effects and its mechanism on nonbacterial prostatitis (NBP) were investigated by Lu and others (2011). Prostatitis is one of the most prevalent conditions in urology encountered in young men and accounts for a significant portion of urologic problems in men older than 50 years of age. The most common type of prostatitis is chronic prostatitis/chronic pelvic pain syndrome (CPPS). The antiprostatitis effect of BSO were evaluated by prostate weight, acid phosphatase, density of lecithin corpuscles, white blood cell count (WBC), and prostatic histomorphological parameters in rats. It was determined that BSO could significantly inhibit absolute weight, prostate index, total acid phosphatase, prostatic acid phosphatase, WBC, and expression levels of 30 up-regulated genes. Histologically, BSO treatment significantly suppressed the severity of the lesion in NBP-induced rats. With the evident contribution of phytosterols and unsaturated fatty acids to inhibit inflammation and prevent prostate diseases (James 2006; Tsai and others 2006), the protective effects of BSO on CP/CPPS are therefore worth investigating. Thus, BSO may be a useful raw material in treating chronic NBP, where it inhibits prostate inflammation in NBP patients by affecting the expression of inflammatory cytokines, their receptors, and related genes (Lu and others 2011). The pronounced hypolipidemic effects of BSO might be attributed to its ability to inhibit cholesterol absorption and increase cholesterol excretion. These results suggest that consuming BSO may provide benefits in managing hypercholesterolemia. Therefore, BSO may be a good candidate for development as a functional food and nutraceutical.

The level of total phytosterols in bamboo shoots ranges from 0.12% to 0.19% on a dry weight basis in different species of bamboos (Sarangthem and Singh 2003a). The concentration of total phytosterols from the initial stage of fermentation (0 d) up to 35 d increases, but later on more or less of a decline in the level of the phytosterol contents occurs. The increase in concentration in fermented shoots may be almost up to double as in *B. balcooa* (increases from 0.18% to 0.61% dry weight) and in *D. hamiltonii* (increases from 0.19% to 0.44% dry weight) (Sarangthem and Singh 2003a, 2003b). The increase in the fermented samples is due to anaerobic digestion by microorganisms that caused degradation of organic matter and resulted in the enrichment of phytosterols (Stahl 1969). Phytosterols are precursors of many pharmaceutically important steroidal products such as corticosteroids, oral contraceptives, antiinflammatory agents, synthetic anabolic steroids, and estrogenic hormones. Thus, succulent bamboo shoots, which are easily available in large quantities, can be used as a source of phytosterols.

Use of foods containing phytosterols is a relatively recent development in human nutrition (Gilbert and others 2005). Phytosterols as functional ingredients in foods appear to be a practical and safe option for lowering cholesterol levels in the population (Quilez and others 2003). Presently, several functional food products, such as spreadable fats, yogurt, and milk, with added free phytosterols or phytosteryl fatty acid esters or phytostanyl fatty acid esters are available in several European countries (Laakso 2005). Techniques have been developed to incorporate plant sterols without affecting food product texture and taste (Nguyen 1999). Phytosterols have been incorporated into margarines, vegetable oils, mayonnaise, fruit juice, yogurt, baked products, meat, soups, and green tea. These bioactive components are also mixed with other functional ingredients such as fiber, beneficial oils, almonds, soy protein, and minerals (Berger and others 2004).

Phenols

Plant phenols are bioactive compounds of interest present in all plants because they are multifunctional and can act as free radical terminators, metal chelators, and singlet oxygen quenchers (Kris-Etherton and others 2002). Phenolic compounds, commonly referred to as polyphenols, are secondary metabolites and their distribution is almost ubiquitous (Pereira and others 2009). They are derivatives of the pentose phosphate, shikimate, and phenylpropanoid pathways in plants. More than 8000 phenolic structures have been identified that range from simple molecules, such as phenolic compounds, to highly polymerized compounds such as tannins (Bravo 1998). These compounds are one of the most commonly occurring groups of phytochemicals that are of considerable physiological and morphological importance in plants as they play an important role in growth and reproduction, protect the plants against pathogens and predators, and contribute toward color and sensory characteristics of fruit and vegetables (Alasalvar and others 2001; Balasundram and others 2006). Experimental evidence shows that phenols possess antiinflammatory, antimicrobial, antithrombotic, cardioprotective, and vasodilatory effects (Benavente-Garcia and others 1997; Middleton and others 2000; Yang and others 2001; Rotelli and others 2003; Mamani-Matsuda and others 2004; Manach and others 2005; Puupponen-Pimia and others 2005; Lehane and Saliba 2008) that are important for good health and disease prevention. These beneficial effects of phenols are due to their strong antioxidant activity wherein they scavenge oxygen radicals and other reactive species (Rice-Evans and others 1997; Parr and Bowell 2000; Heim and others 2002; Dini and others 2006). These features make phenols a potentially interesting material for the development of functional foods (Blando and others 2004). Examples of common phenolic antioxidants include flavonoid compounds, cinnamic acid derivatives, tocopherols, coumarin, and polyfunctional organic acids (Pratt and Hudson 1990; Diplock and others 1998; Vinson and others 1998). Several studies have been carried in order to identify natural phenolics that possess antioxidant activity. Some natural antioxidants have already been extracted from plant sources and are produced commercially (Schuler 1990).

Most research studies have investigated the functional activities of bamboo leaves and stems. It has been determined that the antioxidant capacity of bamboo leaves is due to their high polyphenol content (Lu and others 2006). Butanol extracts of the leaves of *Sasa borealis* exhibited significant antioxidant capacity against 1,1-diphenyl-2-picrylhydrazyl radical (Park and others 2007), ethanol extracts of *P. bambusoides* have nitrite scavenging ability (Lim and others 2004). Kim and others (2001) reported that extracts of bamboo leaves and stems of *Phyllostachys* spp. showed strong antibacterial activities. However, only a few studies have reported on the functional properties of bamboo shoots. Wang and Ng (2003) reported the isolation of an antifungal protein, dendrocin, isolated from the bamboo *D. latiflora*. Bamboo shoots can be a good dietary source of natural phenolic oxidants and dose-dependent inhibitory activity on angiotensin-converting enzyme as determined in 2

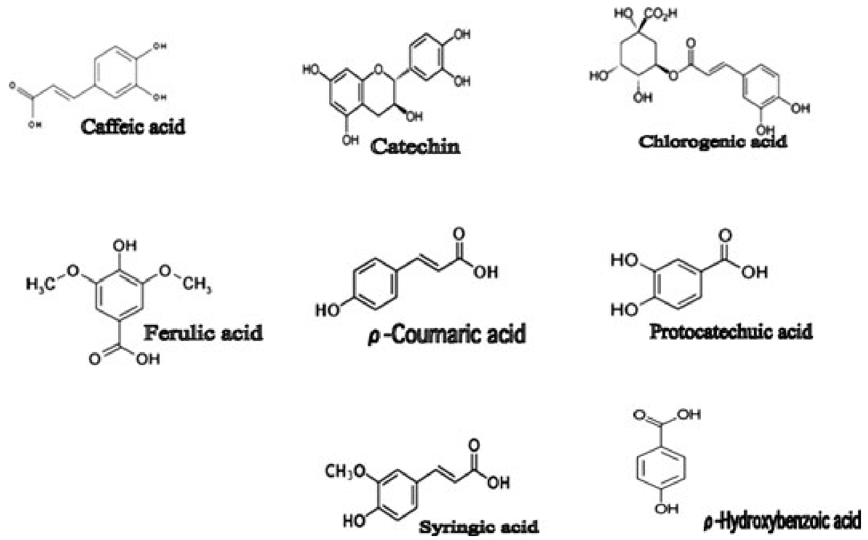


Figure 3–Structures of phenolic compounds present in bamboo shoots.

species of *P. pubescens* and *P. nigra* (Park and Jhon 2010). Eight phenolic compounds, protocatechuic acid, p-Hydroxybenzoic acid, catechin, caffeic acid, chlorogenic acid, syringic acid, p-Coumaric acid, and ferulic acid, were identified by high-performance liquid chromatography (Figure 3). The most important compounds were protocatechuic acid, p-Hydroxybenzoic acid, and syringic acid. It was determined that the antioxidant capacity was highly correlated with the total phenolic contents. A triterpenoid-rich extract was isolated from bamboo shavings, the outer skin of a bamboo culm, and tested on mice to evaluate this bioactive compound. It was demonstrated that the extract has excellent antifatigue, antihyperlipidemic, and antihypertensive activities as determined by change in body weight, weight-loaded swimming test, and climbing test of the mice (Zhang and others 2006). When subjected to toxicological tests, the extract was found to have low toxicity indicating its potential for use in functional food development (Zhang and others 2006; Gong and others 2010).

Antioxidants and antimicrobial compounds have also been isolated from *P. heterocycla* by supercritical CO_2 extraction and subsequent hydrothermal treatment of the residues (Quitain and others 2004). The extract contained 3 predominant ethanol-soluble compounds, identified by MS as an ethoxyquin, a sesquiterpene, and a cyclohexanone derivative. Hydrothermal treatment of extraction residues produced hydroquinone and benzoquinone. Hydroxycinnamic acid, a known antioxidant was also obtained by microwave pyrolysis of extraction residues. Phenolic acids present in the tender shoots have mild antiinflammatory properties and are potent antioxidants that prevent cancer and blood vessel injury that can start atherosclerosis (Belitz and Grosch 1999).

Bamboo shoots also contain tocopherols, which are monophenolic compounds that help to stabilize most vegetable oils. Tocopherols are composed of 8 different compounds belonging to 2 families, namely, tocols and tocotrienols. Tocopherols also possess vitamin E activity and are important biological antioxidants preventing oxidation of body lipids, including polyunsaturated fatty acids and lipid components of cells and organelle membranes. Tocopherols are produced commercially and used as food antioxidants. Kim and others (2007) estimated the tocopherol and carotenoid contents of Korean vegetables including bamboos. In bamboo shoots, they reported α-tocopherol and γ-tocopherol contents to be 0.26 mg/100 g and 0.42 mg/100 g, respectively. Further investigation is needed to identify other bioactive constituents in bamboo shoots.

Types of Bamboo Shoots

Bamboo shoots are available in 3 forms: fresh, fermented, and canned. The fresh shoots are used in households, by processed food makers, and 5-star hotels and specialty restaurants for reasons such as quality, convenience, and price. Besides fresh shoots, canned ones find usage in 5-star hotels and upscale restaurants serving continental and oriental cuisines. However, fermented shoots are less preferred due to their pungent smell, except for avid bamboo eaters.

Fresh shoots

Fresh shoots are collected as soon as the tips emerge from the surface of the soil (Figure 4A). At this stage, the nutrient contents, especially protein, are at their peaks. The shoots vary in size, weight, and degree of bitterness. The most commercially marketed shoots in China, Thailand, and Taiwan are from *B. edulis* (Carriere), *B. oldhamii* (Munro), *D. asper*, *D. latiflorus* (Munro), *P. makinoi* (Hayata), *P. pubescens*, and *Thyrsostachys siamensis* (Gamble). In India, they are from *B. balcooa* (Roxb.), *B. bambos*, *B. tulda*, *Chimonobambusa callosa* ([Munro] Nakai), *C. hookeriana* ([Munro] Nakai), *D. flagellifer* (Munro), *D. giganteus*, *D. hamiltonii*, *D. hookeri* (Munro), and *Melocanna baccifera* ([Roxb.] Kurz.). For consuming fresh shoots, the tough fibrous portion at the basal end of the shoot is cut off and the outer hard leaf sheaths are removed (Figure 4b,c). The tender leaf sheaths inside near the top of the shoot can be left attached as they are tender and full of flavor. After slicing, the shoots are soaked in water for 1 to 2 h or boiled in water for half an hour to remove acridity. They are then ready for use (Figure 4D). If no bitterness is present, they can be used directly as salad or stir-fried like other vegetables. Shoots of some other species such as *B. balcooa*, *B.* (Wall. ex Munro), *B. nutans* (Wall. ex Munro), *B. tulda*, *D. brandisii* ([Munro] Kurz.), *D. hamiltonii*, *D. giganteus*, *D. strictus* ([Roxb.] Nees.), and *T. siamensis* are a little bitter and hence need to be steamed or boiled briefly, or the water is changed and boiled again if bitterness persists. After removing the bitterness, there are many ways to prepare the shoots. Toss and stir-fry with various vegetables or cook alone with butter and seasoning, or marinate the shoots in a mixture of soy sauce, sugar,

Figure 4–(A) Young emerging shoot; (B) harvested young shoots; (C) shoots with outer hard leaf-sheaths removed; (D) sliced shoots.

and rice vinegar before cooking. The shoots can also be frozen or salted, pressed to remove water and dehydrated, or made into pickles.

Fermented shoots

Fermentation, a chemical change produced through the breakdown of carbohydrates and proteins by yeast, bacteria, or molds, is a process used for centuries in order to make and preserve certain types of food. Wine, cheese, beer, yogurt, pickles, ketchup, and sauerkraut are examples of foods that are made through the process of fermentation. Not only is fermentation a process to preserve food, it also adds to the nutrient value, enhances flavor, and improves pharmacological values. The unique microflora in each fermented food increases the protein, vitamin, and fatty acid levels. Probiotics or "good bacteria" are also formed through the process of fermentation.

Fermentation of bamboo shoots involves several steps (Figure 1). Sheaths from the freshly harvested shoots are peeled off, cleaned in water, and cut into small slices (Figure 5A to B). Earthen pots or baskets made of bamboo culms are used as containers for fermentation (Figure 5C to D). When bamboo baskets are used, the inner surface is layered with banana leaves or perforated plastic sheet to drain off the liquid during the fermentation process. The chopped bamboo shoots are put into the container tightly by pressing and are covered with banana leaves or polythene. The shoots are subjected to heavy weights like stones or wooden logs to keep them under pressure. If using pots, sun-dried pots are filled tightly with shoots up to the neck and covered; the bottom is perforated for draining the acidic fermented juice produced during fermentation. The shoots are kept in this condition for 6 to 12 mo. 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* (Giri and Janmejoy 2000; Bhatt and others 2005; Jeyaram and others 2009). No preservative is used and after complete fermentation, the shoots can be stored 1 to 2 y before marketing, thus making them available throughout the seasons. The microorganisms involved in fermentation of bamboo shoots are *Bacillus subtilis, B. licheniformis, B. coagulans*, and *Micrococcus luteus* (Sarangthem and Singh 2003a). It has been shown that the fermented succulent shoots of *B. tulda* and *D. giganteus* are an enriched source of phytosterols and can, therefore, be used as starting material in the production of steroidal drugs (Srivastava 1990; Sarangthem and Singh 2003a). Sitosterols, the most widely distributed phytosterol, are abundant in fermented shoots and have come into prominence because of their easy microbiological conversion into androstadienedione that is an intermediate product in the synthesis of estrone (Sarangthem and Singh 2003b).

Canned shoots

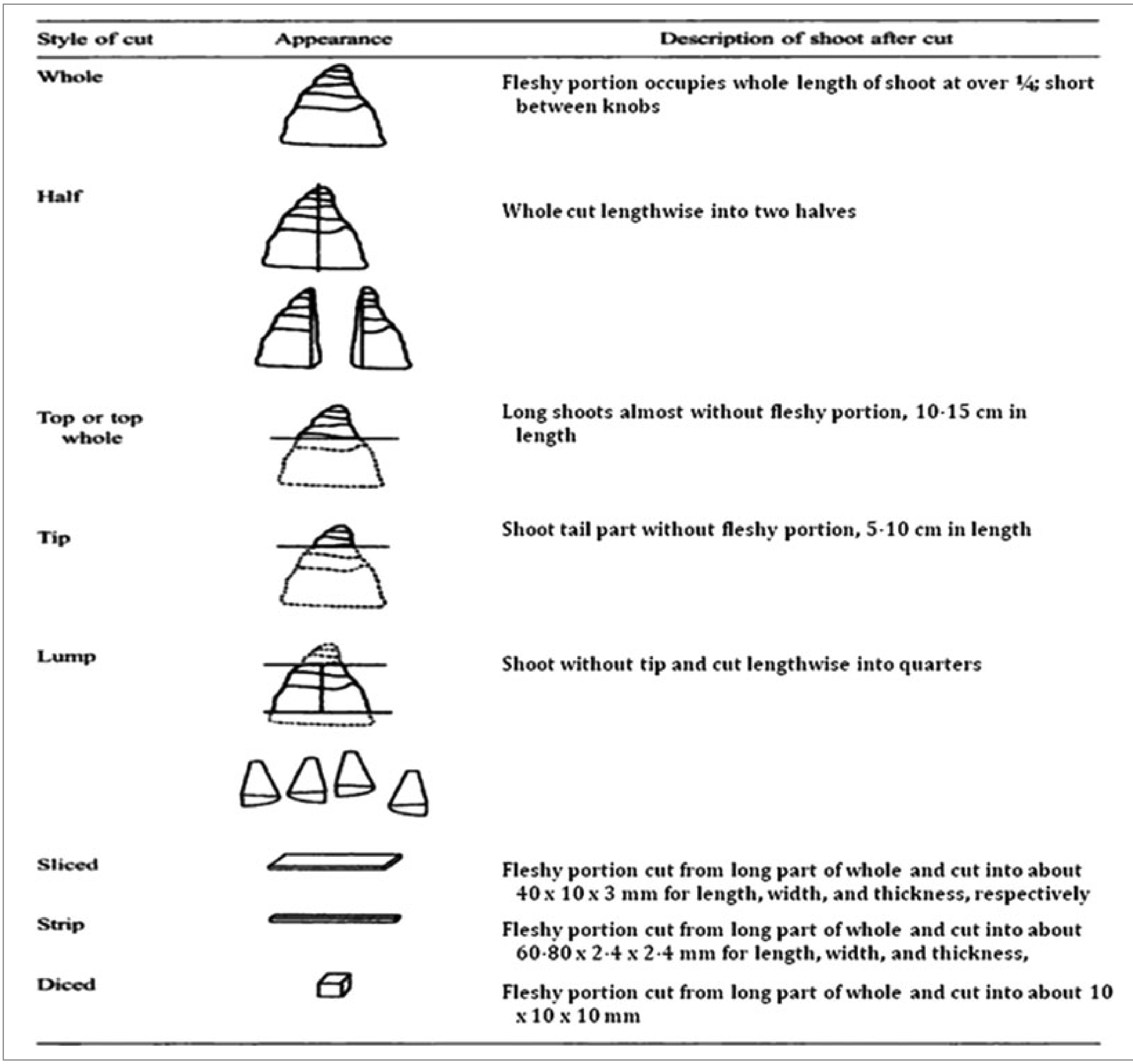
Even though fresh shoots are far superior in taste and texture, bamboo shoots are commonly available in the canned form. The Japanese were the first to develop and use modern technology for the processing of fresh shoots. The shoots are cut in various ways—into halves, thin sliced, stripped, diced, or canned as whole after processing (Figure 6). The processing technique to produce canned bamboo shoot involves crucial steps that must be followed in order to obtain good quality products. This involves boiling the sliced bamboo shoots in water for about 4 h or for 40 to 60 min at 120 °C, cooling, and then storage in brine solution containing usually around 5% to 10% NaCl or more, depending on the species used, and 1% citric acid. Products so processed may be in cans or retort pouches. Cans contain processed fresh materials, while retort pouches contain processed salted or cured materials. Most tinplate canned products are used for cooking, and the pouch products are ready to eat. There are more than 80 companies manufacturing 49 products of canned shoots under various brand names in the world. China, Taiwan, and Thailand are the leading countries supplying canned bamboo products to the world market (Table 7). The canned shoots find markets in Singapore, Malaysia,

Figure 5–Fermentation of bamboo shoots. (A) Freshly harvested and peeled shoots; (B) bamboo shoots cut into slices; (C) bamboo baskets containing shoots for fermentation; (D) earthen pots filled with sliced shoots for fermentation.

Vietnam, United States, Canada, Europe, Australia, and New Zealand (Midmore 1998). In India, there are a few companies such as Tai Industries Limited, Kolkata, that imports and markets canned bamboo shoots from Bhutan and Thailand. Canned shoots find their usage mainly in 5-star hotels and upscale specialty restaurants serving Chinese, Thai, Japanese, Korean, and other continental and Asian dishes. Though fresh shoots are cheaper, the efforts involved in processing fresh shoots have made canned products a convenient choice in some hotels and restaurants. Moreover, they are seasonally available only during the months of May to September. The instances of nonavailability of fresh shoots have persuaded hotels to stock canned products. Thus, convenience to use and availability are the 2 important considerations favoring canned products. The drawbacks of canned shoots are poor shape, loss of aroma and crunchiness, and unknown source of shoots thereby questionable in quality and prompt use within 3 to 4 d after opening the container. In some countries, good species are cultivated to produce shoots of low fiber, and good texture, color, and taste. However, except for the dietary fiber, there is an overall decrease of the nutrient components, especially vitamins and minerals, during canning (Nirmala and others 2008).

Future Prospects

Although the primary role of diet is to provide sufficient nutrients to meet metabolic requirements, recent scientific investigations have revealed that diet may modulate various physiological functions that may play detrimental or beneficial roles in some diseases (Granato and others 2010). Strong health awareness among the human population is creating a genuine need for adopting a nutritionally complete diet, with increasing personalized value of convenience, cost and taste, all emerging as distinguishing variables in the food market (German and others 2004; Wahlgvist 2004). This trend, conspicuous in affluent countries, is spreading to the developing countries as well. Various terms such as "designer foods" (Caragay 1992), "functional foods" (Thomas and Earl 1994), and "nutraceuticals" (De Felice 1995) have been coined to designate foods for health promotion and disease prevention. Broadly, all refer to food or food ingredients that provide medical or health benefits including prevention of diseases. Scientific advances, awareness of personal health deterioration, increasing healthcare costs, busy lifestyles, insufficient exercise, and technical advances in the food industry have stimulated the field of functional foods (Hasler 1996; Siro and others 2008; Granato and others 2010). Today, foods are not intended to only satisfy hunger and provide necessary nutrients for humans but also to prevent nutrition-related diseases and improve physical and mental well-being of consumers (Roberfroid 2000; Menrad 2003). Bamboo shoots, with their high nutritive value and bioactive compounds, hold great promise for utilization as a health food. Unlike most other agricultural crops, bamboos develop naturally with very little artificial selection, are fairly resistant to disease, insects, and climatic injuries, are free from residual toxicity as they grow well without the use of fertilizers and pesticides, and are protected from the surrounding pollutants by several layers of tightly clasped sheaths. They are finding a new place in the spectrum of plant foods used to enhance the quality of life. Functional foods containing phytosterols are now available in the form of margarines, spreads, and salad dressings. Present sources of phytosterols are limited being derived from vegetable oil and tall oil, a by-product of paper production from wood, and it is estimated that 2500 tons of these oils need to be refined to produce 1 ton of phytosterols (Anon 2005). Bamboo, being a fast growing plant, growing 1 m/d, can be an important source of phytosterols. For the future, the addition of plant sterols to foods could be an important public health policy if new technology and economies of scale can lower the cost and enable a greater demand (Law 2000).



Style of cut	Appearance	Description of shoot after cut
Whole		Fleshy portion occupies whole length of shoot at over ¼; short between knobs
Half		Whole cut lengthwise into two halves
Top or top whole		Long shoots almost without fleshy portion, 10-15 cm in length
Tip		Shoot tail part without fleshy portion, 5-10 cm in length
Lump		Shoot without tip and cut lengthwise into quarters
Sliced		Fleshy portion cut from long part of whole and cut into about 40 x 10 x 3 mm for length, width, and thickness, respectively
Strip		Fleshy portion cut from long part of whole and cut into about 60-80 x 2-4 x 2-4 mm for length, width, and thickness,
Diced		Fleshy portion cut from long part of whole and cut into about 10 x 10 x 10 mm

Figure 6–Ways of cutting bamboo shoots for canning.*
*** Source: Ko 2003.**

In contrast to being their routine component of everyday meals of Asian people, in the western countries, bamboo shoots are available only in canned form, imported from other countries. This pattern is, however, now gradually changing; in Europe, shoots are available, though on a small scale, from groves planted near Bordeaux in France, Carasco in Italy, and New South Wales in Australia. But, since the local produce is not sufficient to meet the market demand, bamboo shoots in Western markets and Australia are usually imported in processed form. The bamboo shoot-based industry is expanding rapidly in many Asian countries, mainly in China, Japan, Korea, the Philippines, and Thailand, where bamboo farming for edible shoot production is well-established and generating good income for the growers. Nearly, 90 bamboo shoot-based enterprises exist in the Zhejiang province of China, and there are 25 canning companies in the Prachinburi province of Thailand (Thammincha 1998). Canned bamboo shoots occupy an important place in Thailand's global trade providing export earnings of about US$ 30 million annually. In India, despite the rich bamboo genetic resources, edible bamboo species in the country

Table 7–Estimated bamboo shoot annual import/export statistics for major countries.*

	Import (tons)		Export (tons)	
Country	Canned	Fresh/frozen	Canned	Fresh
Australia	12000	–	–	–
Japan	130000	4000	–	–
USA	44000	–	–	–
Taiwan	5000	–	38500	1500
China	–	–	143000	7000
Thailand	–	–	68000	–
Others	99000	6000	40500	1500
Total	290000	10000	290000	10000

*Source ERG 2004.

are presently not raised for shoot production, being confined to only certain pockets of the country. There is a perceptible, untapped demand for bamboo shoots in countries such as Japan, Denmark, Australia, the Philippines, Malaysia, and Singapore. Japan imports 0.13 million tons of canned shoots and 3400 tons of fresh shoots annually, whereas Australia imports about 6 to 12000 tons of canned shoots annually (Midmore 1998). India has a substantial price advantage in edible bamboo exports. The local market price of fresh bamboo shoots during the peak season is generally U.S. dollar 0.23 to 0.27 per kg. In contrast, bamboo prices in Japan range from U.S. dollar 1.5 to 3. During the off-season, prices shoot up to U.S. dollar 4 to 6 per kg. This price factor is exploited by Chinese bamboo growers who manipulate their shoot production season by laying steam pipes under the soil surface of their bamboo fields. Export markets have their own preferences as far as the shape, size, and weight of bamboo shoots are concerned. India with its vast bamboo resources has considerable scope for cultivation of edible bamboo species in several areas of the country. If bamboos are popularized as food and commercial production is taken up on a large scale, it will contribute enormously to rural economies and boost export earnings.

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