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Review

Bamboo shoot processing: food quality and safety aspect (a review)

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Bamboo shoot being low in fat, high in dietary fibre and rich in mineral content, like an ideal vegetable has been used traditionally by tribals for decades, world over. The research studies included in this review paper focus on post harvest processing of bamboo shoot. Due to seasonal availability of bamboo shoot, processing for handling cynogenic toxicity in raw shoot while keeping nutrients intact and enhancement of shelf life of the value added products assume great significance for business potential. Obviously, it would demand process standardization for small scale processing units. Literature review reveals that studies on food safety aspect of bamboo shoot are unsystematic and scanty, hence need special attention. Similarly indepth investigation on effect of processing (boiling, fermenting, canning etc.) on total nutrient content (macro and micro) of various bamboo shoot species growing in different agro-ecological regions needs to be carried out. It would help in converting the non-edible species into edible one, thus enhancing the business scope for rural people. Scientific validation of indigenous knowledge of tribals coupled with modern scientific inputs would provide guidelines for evolving a simple, efficient system for bamboo shoot utilization. Thus, several important knowledge gaps identified in this paper would give impetus to new academic and R&D activities, in turn generating innovative job profile in food industries as well as rural entrepreneurship.

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Introduction

Bamboo, the giant grass of subfamily *Bambusoideae* of *Poaceae*, is almost ubiquitous. One of the oldest plants on Earth, bamboo is grown, throughout the world and has uses from cradle to coffin. More than 1250 species, belonging to 75 genera, are being reported worldwide, to which India has contributed more than 125 species belonging to 23 genera. India is also one of the leading countries of the world, covering an area of bamboo forest around 10.03 mha, which accounts 12.8% of the total forest cover in the country (Biswas, 1994).

Bamboos play an important role in daily life of rural people especially tribals in numerous ways, from house construction, agricultural implements to provide food, fodder etc. The edible parts of bamboo, i.e. shoot has a high nutritive content. Presence of high quality vitamins, carbohydrates, proteins and minerals in bamboo shoot and their easy availability to common man may help in solving nutritional deficiency of rural poor (Tripathi, 1998). All this indicates vast potential of bamboo shoot as food resource. In the present paper various bamboo shoot processing methods (including traditional) and their effect on nutritive value of processed shoot, technological systems for removal of toxic constituent in shoot, have been discussed. Available methods of bamboo shoot drying of this non-forest produce have been compiled and discussed. Future R&D areas in relation to above aspects for enhancing quality control have been identified.

Food potential of bamboo shoot

The value of bamboo shoot as food is based not only on its total fresh weight, but also on the edible portion, which amounts to about 27%. Most of the species growing in Thailand produce edible shoots, the best one are *Dendrocalamus asper*, *Dendrocalamus giganteus*, *Dendrocalamus merrillianus*, *Bambusa tulda*, *Pseudoxytenanthera albociliata* and *Thyrsostachys siamensis*. In Japan more than 8000 tonnes of shoots are consumed every year and the main source is *Phyllostachys pubescens*. About 400 tonnes of shoots are canned and exported to Japan from Thiland. *Phyllostachys edulis* and *D. latifera* are the main edible bamboo species in Taiwan (Tripathi, 1998). In India, shoots of *Bambusa bambos*, *B. multiplex*, *B. tulda*, *B. vulgaris*, *D. giganteus*, *D. hamiltonii*, *D. longispathus*, *D. strictus* and *Sinobambusa elegans* are used as vegetables and pickle products. A comprehensive list of edible bamboo species growing world over has been prepared by Vatsala (2003).

Analysis of nutritive value of bamboo shoots have been performed by several researchers (Bhargava, Kumbhare, Srivastava, & Sahai, 1996; Bhatt, Singha, Singh, & Sachan, 2003; Bhatt, Singh, & Singh, 2005; Chen, Qiu, Huang, Fan, & Jiang, 1999; Giri & Janmejay, 1992; Kumbhare & Bhargava, 2007; Nirmala, David, & Sharma, 2007; Nirmala, Sharma, & David, 2008; Qiu, Shao, Zhang, Hua, & Bao, 1999; Satya, Singhal, Prabhu, Bal, & Sudhakar, 2009b; Sharma, Nirmala, Richa, & David, 2004; Shi & Yang, 1992; Tripathi, 1998). A beautiful systematic compilation on nutritive value of shoots harvested from ∼20 bamboo species may be mentioned in this context (Satya, Singhal, Bal, & Sudhakar, 2009a).

Bamboo shoot contains about 88.8% water, more than 3.9% protein and 17 amino acids. Amino acid content of bamboo shoot is much higher than found in other vegetables such as cabbage, carrot, onion and pumpkin. Eight kinds of amino acids that are not synthesized in human body have to be supplied from food items and surprisingly almost all these are available in bamboo shoots. Bamboo shoot contains 17 different types of enzymes and over 10 mineral elements such as Cr, Zn, Mn, Fe, Mg, Ni, Co, Cu etc. In view of these essential characteristics (low in fat, rich in vitamins, special amino acids, minerals, dietary fibre etc.), bamboo shoot is considered an ideal vegetable for healthy diet (RFRI, 2008).

Bamboo shoot processing

Traditional knowledge system

Ethnological surveys of food practices of using bamboo shoot by different community in India have been reported. However, global studies on traditional methods for processing of bamboo shoot are very limited. Based on the available information/literature details on these products and processes are presented here.

International scenario

In Australia and New Zealand fresh bamboo shoots are sliced into strips, boiled in lightly salted water for 8–10 min before consumption. In Thailand and Vietnam some shoots are finely grated and used in salads. In Japan, shoots are sometimes boiled whole for more than 2 h (Anonnymous, 2004).

Recently, traditional methods of bamboo shoot processing by indigenous community in China and Thailand have been reported. In Xishuangbanna, Yunan Province in China, shoots of *D. hamitonii*, *Dendrocalamus semiscandens*, and *Schizostachyum funghomi* have been used for cooking, while bitter shoots of *D. giganteus*, *Dendrocalamus barbatus*, *Dendrocalamus membranaceus*, *Pseudostachyum polymorphum*, *Gigantochloa nigrociliata*, *Leptocanna chinensis* are considered good for making acid bamboo shoot and dry shoot (Qing *et al.*, 2008). The *Sao* community, Sai Yoke district of Bangkok preserves shoots (*T. siamensis*) by packing them in plastic bag and steaming by different processes and durations. It is reported that bamboo shoots which are preserved in plastic bag, may be contaminated by chemicals present in the plastic material (Chiangthong & Chayawat, 2009).

Indian scenario

Some popular ethnic fermented bamboo shoots in North-Eastern India are *Mesu* in Sikkim, *Soidon, Soibum* and *Soijim* in Manipur, *Ekung, Eup* and *Hiring* in Arunachal Pradesh, *Lung-siej* or *Syrwa* in Meghalaya (Tamang, 2005).

Kandha tribe of Kalahandi, Orissa consumed fresh sliced bamboo shoot named as *Kardi*. These pieces are dipped in water for a day for fermentation to wash off bitterness before cooking. It is also sometimes pounded in mortar and pestle, then sun dried, which is called as *Handua* (Panda & Padhy, 2007). A field survey was carried out in five villages of Sambalpur, Orissa and found that for removal of acrid taste, bamboo shoot is boiled in water and extract being toxic is discarded (Bal, Naik, & Satya, 2009).

Singh, Singh, and Sureja (2007) have made special efforts to dig out traditional knowledge of tribals in Arunachal Pradesh. Ziro district of Arunachal Pradesh, *Apatani* tribes prepare varieties of fermented food products viz. *Hikhu, Hiring* and *Hithyi* from bamboo shoots. Fermentation is done by keeping chopped shoots after peeling in bamboo basket covered inside and top with banana leaves over 6–8 days. *Hithyi,* sun dried sliced shoots stored in bamboo basket. Also, *Adi* tribes of East Siang, Arunachal Pradesh prepare bamboo shoots into three major forms: *Ekung* (fermented shoot), *Eyup* (dried shoots) and *Eting* (fresh shoot) (Singh *et al.*, 2007).

Meitei community, Manipur avoid washing of bamboo shoot during processing due to loss of natural flavour and taste. Sliced shoots are dried in sunlight for 10–15 min and kept in earthen pot for fermentation (2–3 months) by adding small amount of water and salt. Then shoots are taken out and dried in sunlight to about 50% moisture content. Then dried pieces are kept and mixed in basket made of cane/bamboo for further drying. Barman community of Tripura prepares traditional food called *Godhak*, from bamboo shoot by adding pseudostem of banana, dry fishes, salt, chilli, onion and garlic (Singh *et al.*, 2007).

All the above indigenous knowledge of tribal community needs to be scientifically validated to further improve the process efficiency.

Processing methods and nutritional value of bamboo shoot

Different processing methods such as fermentation, roasting, boiling, blanching, canning, pickling etc. have been reported as bamboo shoot are consumed in the form of fermented-slice, crushed-fermented moist, crushed-fermented dry, fermented whole shoot, roasted whole shoot and boiled whole shoot etc. Major research work on this aspect has been carried out during the past 2–3 years only (Kumbhare & Bhargava, 2007; Nirmala *et al*., 2008). These studies seem to be insufficient to draw any significant conclusion, but certainly provide guidelines for indepth scientific work on this important aspect of food quality. Therefore nutritive content in raw, boiled, fermented and canned (non-salted) bamboo shoots of 5 commonly used species have been compiled and compared in Table 1.

Data in Table 1 reveals following interesting findings.

The moisture content (g/100 g fresh wt) is highest in canned shoots (95.16) followed by fresh (90.70) and fermented shoots (88.83). This is because canned shoots are stored in preservative liquid generally in metallic cans.

Carbohydrate, an ideal source of energy was found to be 3.3, 3.4, 2.6 and 2.9 g/100 g fresh wt, in raw shoots of *B. nutans, B. vulgaris, Dendrocalamus strictus, D. asper* respectively. The content increased after boiling (5.1, 5.0, 5.0 and 3.1 respectively) (Kumbhare & Bhargava, 2007) but substantial decrease (~72%) was noted after fermentation and canning in *Dendrocalamus giagnteus* as compared to raw shoots (Nirmala *et al*., 2008). During boiling the polysaccharides may get hydrolyzed into simple sugars and resultant monosaccharides contribute to this increase (Kumbhare & Bhargava, 2007).

The reducing sugar content has not been widely studied. Only one researcher found that the content in raw shoots was 1.05, 0.81, 0.72 and 1.14g/100 g fresh wt in *B. nutans, B. vulgaris, D. strictus, D. asper* respectively and the content decreased on boiling and highest reduction of 91.2 % in case of *D. asper* and lowest reduction of 27.25% in case of *B. vulgaris* was noted. This reduction is due to prolonged heating at high temperature resulted in degradation of sugars (Kumbhare & Bhargava, 2007). From nutritional point of view it is an advantage as a high proportion of the unassimilable raffinose and related sugars included in that sugar fraction are reduced by boiling shoots.

The ash content decreased on boiling, fermentation and canning of bamboo shoot. On boiling major reduction of 20% was found in case of *B. nutans* and lowest of 6.2% in case of *D. asper*. But the reduction is not so pronounced in fermentation (12%) and canning (15%) (Kumbhare & Bhargava, 2007; Nirmala *et al*., 2008).

The crude fibre content reported by Kumbhare and Bhargava (2007) was not found to change upon boiling but increased significantly both in fermented and canned shoot as reported by Nirmala *et al*. (2008) in *D. giganteus*. The author also calculated different fractions of crude fibre and reported that fermented shoots have more amount of acid detergent fibre (3.28 g/100 g fresh wt) than the canned (2.02 g/100 g fresh wt) as well as the raw shoots (2.15 g/100 g fresh wt). Lignin content in both the raw and canned shoots was less than the fermented shoots. The canned shoots (1.02%) have a comparatively higher content of hemicellulose than the fermented (0.9%) as well as the raw shoots (0.5%). The fermented shoots have higher amounts of cellulose (18.5%) than the raw shoots while canned shoots have lower amount of cellulose than both the fresh and fermented shoot.

Crude protein content in the above bamboo species ranged from 19.2 to 25.8 g/100 g dry wt (Kumbhare & Bhargava, 2007; Satya *et al*., 2009b). The content decreased upon boiling the shoots by 25% due to denaturaion of protein. Amino acids were also examined by some researchers and it was found that total free amino acids (equivalent of leucine) were found to decrease in all the three cases of processed shoots (Kumbhare & Bhargava, 2007; Nirmala *et al*., 2008). Prolonged heating at high temperature degrades the amino acids. This may be the possible cause for decrease in amino acid content. The major change in amino acids that occurs on cooking is due to Maillard reaction which makes lysine unavailable, thereby reducing nutritive value. Loss of free amino acids also takes place through leaching or may react with sugars to form complexes (Meredith & Dull, 1979).

The fat content was observed to be very low in all the species tested by Kumbhare and Bhargava (2007). *D. strictus* was found to have the lowest content of 0.1 g/100 g fresh wt. The content further decreased in fermented and canned shoots and thus making it more beneficial for patient requiring fat free food. Bhatt *et al*. (2005) reported the highest value of fat in *B. nutans* to be 1.0 g/100 g fresh wt and Sharma *et al*. (2004) reported the lowest value as 0.1 and 0.2 g/100 g fresh wt in *B. vulgaris* and *D. strictus* respectively.

Studies on vitamin C and E are very scarce, only one researcher tried to find out the content in raw, fermented and canned shoots in *D. giganteus*. The vitamin C and E content was 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). Bhargava *et al*. (1996) reported a higher value of vitamin C (13.7 mg/100 g shoots) in *B. vulgaris*. This high value may be because the sample taken was a mixture of shoots and leaves.

Nirmala *et al*. (2008) also looked at the trace elements like Cd, Co, Cu, Mg, Mn, Ca, Fe, K, P, Na and Se. The fermented shoots possess nearly same amount of Cd, Co, Mn, Ni, P and Se content as the raw shoots. However, Cd, Co, Cu, Mg, Mn and Na content in canned shoots were lesser than in fermented shoots.

Above discussion clearly indicates the need of further investigation on nutrient composition of freshly harvested and differently processed shoots from different agro-ecological regions. Scientific inputs along with existing traditional practices may provide a new insight into the processing-nutrition matrix.

Toxic content in bamboo shoot

Bamboo shoots contain potentially toxic compounds called cyanogenic glycosides i.e. Taxiphyllin, which break down upon disruption of plant cells to form hydrogen cyanide (Anonnymous, 2004). Bamboo plant produces

Table 1. Nutrient content of raw, boiled, fermented and canned (non-salted) bamboo shoots.

Nutrients	Species	Shoot nature				References
		Raw shoots	Boiled shoots	Fermented shoots	Canned shoots (non-salted)	
Moisture (g/100 g fresh wt)	*B. nutans*	94.70	–	–	–	Bhatt *et al.* (2005)
	B. vulgaris	77.00	–	–	–	Bhargava *et al.* (1996)
		93.35				NRFBT (2008)
	D. strictus	85.98	–	–	–	NMBA (2009)
		93.22	–	–	–	NRFBT (2008)
	D. asper	89.40	–	–	–	Nirmala *et al.* (2007)
	D. giganteus	90.70	–	88.83	95.16	Nirmala *et al.* (2008)
Carbohydrates (g/100 g fresh wt)	*B. nutans*	3.30	5.10	–	–	Kumbhare and Bhargava (2007)
	B. vulgaris	3.40	5.00	–	–	
	D. strictus	2.60	5.00	–	–	
	D. asper	2.90	3.10	–	–	
	D. giganteus	5.10	–	1.50	1.45	Nirmala *et al.* (2008)
Reducing sugars (g/100 g fresh wt)	*B. nutans*	1.05	0.10	–	–	Kumbhare and Bhargava (2007)
	B. vulgaris	0.81	0.59	–	–	
	D. strictus	0.72	0.51	–	–	
	D. asper	1.14	0.10	–	–	
	D. giganteus	–	–	–	–	Nirmala *et al.* (2008)
Ash (g/100 g fresh wt)	*B. nutans*	0.90	0.72	–	–	Kumbhare and Bhargava (2007)
	B. vulgaris	0.80	0.66	–	–	
		0.88	–	–	–	NRFBT (2008)
	D. strictus	0.90	0.82	–	–	Kumbhare and Bhargava (2007)
		1.03	–	–	–	NRFBT (2008)
	D. asper	0.80	0.75	–	–	Kumbhare and Bhargava (2007)
	D. giganteus	0.89	–	0.78	0.75	Nirmala *et al.* (2008)
Crude-fibre (g/100 g fresh wt)	*B. nutans*	0.76	0.75	–	–	Kumbhare and Bhargava (2007)
	B. vulgaris	0.97	0.97	–	–	
	D. strictus	0.98	0.96	–	–	
	D. asper	0.71	0.70	–	–	
NDF (g/100 g fresh wt)	*D. giganteus*	2.65	–	4.18	3.04	Nirmala *et al.* (2008)
ADF (g/100 g fresh wt)	*D. giganteus*	2.15	–	3.28	2.02	
Lignin (g/100 g fresh wt)	*D. giganteus*	0.56	–	1.40	0.78	
Hemicellulose (g/100 g fresh wt)	*D. giganteus*	0.50	–	0.90	1.02	
Cellulose (g/100 g fresh wt)	*D. giganteus*	1.59	–	1.89	1.24	
TFAA (g/100 g fresh wt), (TFAA: Total free amino acid, % equivalent of leucine)	*B. nutans*	0.11	0.19	–	–	Kumbhare and Bhargava (2007)
	B. vulgaris	0.46	0.22	–	–	
	D. strictus	0.70	0.09	–	–	
	D. asper	0.15	0.06	–	–	
	D. giganteus	0.12	–	0.08	0.08	Nirmala *et al.* (2008)
Crude protein (g/100 g dry wt)	*B. nutans*	21.10	17.30	–	–	Kumbhare and Bhargava (2007)
	B. vulgaris	25.70	13.50	–	–	
		20.60	–	–	–	Satya *et al.* (2009b)
	D. strictus	21.51	–	–	–	
		19.20	17.10	–	–	Kumbhare and Bhargava (2007)
	D. asper	25.80	11.60	–	–	
	D. giganteus	–	–	–	–	Nirmala *et al.* (2008)
Vitamins C (mg/100 g fresh wt)	*B. nutans*	5.30	–	–	–	Bhatt *et al.* (2005)
	B. vulgaris	13.70	–	–	–	Bhargava *et al.* (1996)
		5.00	–	–	–	Satya *et al.* (2009b)
	D. strictus	5.80	–	–	–	
	D. asper	3.20	–	–	–	Nirmala *et al.* (2007)
	D. giganteus	3.28	–	1.09	1.80	Nirmala *et al.* (2008)

Table 1 (*continued*)

Nutrients	Species	Shoot nature				References
		Raw shoots	Boiled shoots	Fermented shoots	Canned shoots (non-salted)	
Vitamins E (mg/100 g fresh wt)	*B. nutans*	–	–	–	–	
	B. vulgaris	–	–	–	–	
	D. strictus	–	–	–	–	
	D. asper	0.91	–	–	–	Nirmala *et al.* (2007)
	D. giganteus	0.69	–	0.21	0.30	Nirmala *et al.* (2008)
Fat (g/100 g fresh wt)	*B. nutans*	1.00	–	–	–	Bhatt *et al.* (2005)
	B. vulgaris	0.20	–	–	–	Sharma *et al.* (2004)
	D. strictus	0.10	–	–	–	
	D. asper	3.54	–	–	–	Nirmala *et al.* (2007)
	D. giganteus	0.39	–	0.32	0.25	Nirmala *et al.* (2008)

cyanoglycosides and also a corresponding hydrolytic enzyme (beta-glycosidase), which are brought together when cell structure of the plant is disrupted by a predator, with subsequent breakdown to a sugar and a cyanohydrin, that rapidly decomposes to hydrogen cyanide and an aldehyde or a ketone which is shown in Fig. 1 (Moller & Seigler, 1999).

It is reported that bamboo shoot contains cyanide as high as 0.8% (Poulton, 1983), 0.3% (Tripathi, 1998) and 0.1% (Anonnymous, 2004). However, cyanide content is reported to decrease substantially following harvesting. Also cyanide content often varies in different parts of a shoot and between the same parts of different individuals of the same species. Bamboo shoots contain up to 0.16% total cyanide in the tip reducing to 0.01% in the base (Haque & Bradbury, 2002). Also, homogentisic acid is responsible for disagreeable pungent taste of shoot (Bhargava *et al*., 1996). Recently, Satya *et al*. (2009b) has reported cyanide content in four Indian bamboo species namely *D. strictus, B. tulda, B. vulgaris* and *B. balcoa*. The acute lethal dose of HCN, in mg kg^{-1} body weight, for humans is 0.5–3.5 (Halstrom & Moiler, 1945). So, approximately 50–60 mg of free cyanide from bamboo shoot constitutes a lethal dose for an adult man.

Processing methods for toxicity removal

Various indigenous methods of reducing acidity/bitterness from fresh bamboo shoots has been reported and some of them include chopping of tender shoots into small pieces, partial drying of fresh shoots, boiling in water/salt water and draining or keeping shoots in hot water for 10–15 min or in water for a week at ambient temperature, etc.

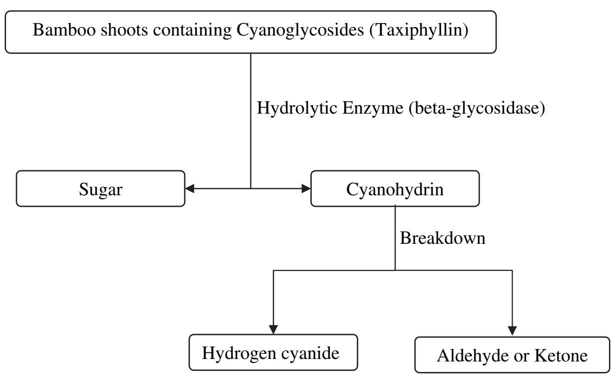

Fig. 1. Hydrogen cyanide generation in bamboo shoot.

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 (Bhardwaj, Singh, Wangchu, & Sureja, 2005). Similarly Singh *et al*. (2007) reported unique traditional processing of bamboo shoot fermentation to reduce cyanide percentage.

Ferreira, Yotsuyanagi, and Carvalho (1995) reported the optimum cooking conditions that resulted in 97% reduction of HCN were 98–102 °C for 148–180 min. Subsequently, Tripathi (1998) mentioned that removal of HCN can be done by steaming bamboo shoot. Bhargava *et al*. (1996) reported removal of this during cooking shoots by changing water several times or by presoaking for a long time by subsequent changing 2% salt solution. Recently, Wongsakpairod (2000) reported superheated steam drying removes HCN from bamboo shoot as Taxiphyllin decomposes at around 116 °C.

Bamboo shoot drying: a future perspective

Most of food and agro-products of biological origin are heat sensitive. So, it is important to reduce their water activity to increase shelf life without degrading their quality attributes. Thus, lots of emphasis is being given to drying technology. However, very little work is available on bamboo shoot drying. Hence in order to see the scope of future R&D works a comparative study of various bamboo shoot drying methods along with their advantages and disadvantages has been visualized and presented in Table 2.

Muchtadi and Adawiyah (1996) worked on drying of bamboo shoot (*D. asper*) in a cabinet dryer at 60 °C for 7–8 h. The comparison of proximate analysis of bamboo shoot (Table 3) shows a significant decrease in starch (67.5%) and in ascorbic acid (88.9%). Starch in leucoplast was gelatinized during drying process, while ascorbic acid dissolved in water and was unstable at high temperature.

Table 2. Comparative study on bamboo shoot drying methods.

S. No.	Drying methods	Remarks	References
1	Drying in a cabinet dryer at 60 °C for 7–8 h	Significant decrease of 67.5% in starch and 88.9% in ascorbic acid	Muchtadi and Adawiyah (1996)
2	Comparison of superheated steam (SSD) with low-temperature and high-temperature hot air drying	➢ Boiling or blanching, required prior to drying to reduce bitterness of bamboo shoot is eliminated. ➢ Color of bamboo shoots dried using superheated steam (120–160 °C) is darker than color obtained from hot air even at same drying temperature. ➢ Best color of bamboo shoots (lightest color) obtained by low- temperature drying (at 70 °C). ➢ Sensory tests indicated that bitterness of bamboo shoots was also eliminated.	Wongsakpairod (2000)
3	Comparison of traditional convective hot airflow drying (AD) with vacuum freeze drying (FD)	➢ AD products extremely hard texture, severe browning, low rehydration rate, low nutritive value ➢ FD is good at preserving color, aroma, taste and shape ➢ But high operating costs, high energy consumption and low production yield make FD expensive compared with others ➢ AD has lower energy consumption, higher yields than other drying methods	Li *et al.* (2002)
4	Hot air drying	➢ Linear relationship between volume change and moisture content ➢ Shrinkage of bamboo shoot parallel to its fibers is different from that occurring perpendicular to its fibers	Madamba (2003)
5	Two-stage hybrid method of drying: hot airflow drying followed by vacuum freeze drying (AFD), reverse of the process i.e. vacuum freeze drying followed by hot airflow drying (FAD)	➢ Quality of dehydrated bamboo shoot slices after AFD was worse than for single convective hot airflow drying (AD) or vacuum freeze drying (FD) ➢ Dehydrated bamboo shoot slices from FAD were superior to those from AD in terms of sensory, nutrition, cell structure ➢ Quality of dehydrated bamboo shoot slices from FAD was similar to that from FD ➢ Gross energy consumption for FAD was 21% lower than for FD ➢ FAD was effective for improving quality of dehydrated bamboo shoot slice and for saving energy	Xu *et al.* (2005)

Wongsakpairod (2000) compared superheated steam, low-temperature and high-temperature hot air drying of bamboo shoots, both in terms of drying kinetics and dried product quality. The process of boiling or blanching, which is generally required prior to drying to reduce bitterness of shoot (by decomposing Taxiphyllin, which causes bitterness), is eliminated when superheated steam drying is employed. It was found that colour of shoots dried using superheated steam (120–160 °C) is darker than shoots dried using hot air even at same drying temperature and the best colour (lightest colour) was obtained at 70 °C.

The traditional convective hot airflow drying (AD) has advantages of lower energy consumption, easier control of production conditions and higher yields than other drying methods. However, there are lots of shortcomings of extremely hard texture, severe browning, low rehydration rate, low nutritive value of products. Vacuum freeze-drying (FD) is very good at preserving colour, aroma, taste and shape of foods. However, high operating costs, high energy consumption and low production yield make FD process very expensive which greatly restrict its application (Li, Qiu, & Yang, 2002).

Madamba (2003) also reported a linear relationship between dimensionless volume change and moisture content during hot air drying of bamboo shoot. Shrinkage of bamboo shoot parallel to its fibers was different from perpendicular to its fibers. Recently, Xu *et al*. (2005) studied the efficacy of different freeze drying methods of bamboo shoots. To obtain dehydrated shoot slices of high quality, a two-stage hybrid drying techniques i.e. (a) hot airflow drying followed by vacuum freeze drying (AFD) and (b) reverse of the process i.e. vacuum freeze drying followed by hot airflow drying (FAD) were examined. Dehydrated bamboo shoot slices from combined FAD were superior to those from single AD in terms of sensory, nutrition, cell structure and rehydration ratio aspects. Gross energy consumption for combined FAD was 21% lower than for single FD.

It may be noted that in selecting an appropriate drying technology, it is important to examine energy, environmental as well as cost issues. Different technologies may be appropriate at different geographical locations depending on local socio-cultural conditions. Recently, Preliminary study in bamboo based cost effective solar dryer carried out at IIT Delhi (Sudhakar & Sharma, 2008) has indicated that a continuous drying of shoot at steady and moderate temperature of 40–75 °C can be done with solar dryer having latent heat storage in phase change materials. However, quality of end product using these hybrid systems needs to be ensured. In future, it is anticipated that renewable energies (e.g. solar, biomass) will become increasingly significant sources of energy. In some cases, use of hybrid technologies, such as solar-assisted heat pump dryer, solar dryer with thermal energy storage, microwave assisted drying may be more cost effective.

Table 3. Comparison of the proximate analysis of bamboo shoot.

Compound	Fresh shoot	Dried shoot	% Decrease
Water (g/100 g fresh wt)	92.6	4.6	95.1
Protein (g/100 g dry wt)	27.8	21.6	22.2
Starch (g/100 g dry wt)	28.3	9.2	67.5
Fibre (g/100 g dry wt)	5.2	5.0	4.6
Ascorbic acid (g/100 g dry wt)	2.1	0.2	88.9

Source: Muchtadi and Adawiyah (1996).

Conclusions and future prospects

There are more than one thousand bamboo species being utilized in numerous ways among different cultures, world over. The current research on this extraordinary material is very fascinating leading to emergence of new avenues of bamboo utilization including food and pharmaceutical potential. Though bamboo shoot is low in fat and calories yet rich in various nutrients and edible fibres. Therefore, potential of edible bamboos in supplementing nutrients in diet of even elite people has attracted attention of researchers. Analysis of published literature revealed a number of advanced methods for bamboo shoot processing and drying. For example, superheated steam drying of bamboo shoots eliminated boiling or blanching for reducing bitterness of shoots by decomposing Taxiphyllin and simultaneously preserving nutrients. Similarly, one important aspect during hot air drying of bamboo shoot is shrinkage of shoot parallel to its fibers differ from perpendicular to its fibers. So, expressing deformation in terms of degree of shrinkage (or volume shrinkage ratio) is not adequate, hence a new perspective of quality control in case of bamboo shoot is required. Interestingly, inspite of the fact that bamboo shoot has been an integral part of diet of tribal community, scientific validation of traditional processing methods in terms of food quality and safety has not been attempted. The integration of traditional processes after scientific validation would go a long way in developing a suitable system for storage and preservation of this perishable commodity for rural entrepreneurship. Also, processing techniques to take care of the food safety aspect would enhance the export potential of this wonderful product. Preservation methods such as boiling, canning, drying, fermentation etc. have to be standardized for eliminating toxic content while keeping the nutritional properties intact. Infact R&D work on developing suitable processing methods for converting non-edible species into edible one would open new avenues for tapping the huge potential of this natural product. In this context, efficacy of discarded toxic extract as biopesticide needs to be explored. The use of hybrid technologies, such as solar-assisted heat pump dryer, solar dryer with thermal energy storage, microwave assisted drying may be more cost effective to get the desired quality products. In order to design appropriate machinery for processing of bamboo shoot such as slicing, striping, sizing, physical characteristics especially shear properties play very important role. Surprisingly, technical data on such physical properties of bamboo shoot are very limited, hence R&D work on this important aspect is warranted.

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