Journal of Postharvest Technology
2022, **10**(1): 1-11
www.jpht.in

RESEARCH ARTICLE

Effect of drying processes on nutrients and bioactive components of edible bamboo (*Phyllostachys mannii* Gamble) shoots growing in Meghalaya, India

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Received: 22.09.2021 Accepted: 29.11.2021

ABSTRACT

Juvenile shoots of bamboo (*Phyllostachys*) are the most superior quality vegetable used in various culinary purposes throughout the world. Shoots contain high moisture content and have short shelf life of 2-3 days. Thus, processing techniques are required to prevent post-harvest losses and long-term storage of shoots. In the present study, *Phyllostachys mannii* Gamble was subjected to different drying processes i.e. freeze (-55ºC for 24 hrs), oven (60ºC for 24 hrs) and sun (32-40ºC for 16 hrs) to select the best drying method in terms of retention of nutrients and bioactive components. Results indicated that shoots had high amount of protein, minerals, amino acids, dietary fiber, phenols and phytosterols and low amount of fat, vitamin E. Fourteen minerals and twenty amino acids were detected, of which minerals namely K, P, S, Mg, Si, Fe, Zn and amino acids namely asparagine, tyrosine, valine and leucine were found in abundant. Results showed that freeze drying was better in retaining maximum amount of macronutrients, amino acids, dietary fibers and phenols. However, sun drying was effective in retaining maximum amount of macrominerals except K, Cl, Na and microminerals which showed no significant variation in sun and freeze-dried samples.

Keywords: Bamboo shoots, bioactive components, drying, nutrition, *Phyllostachys mannii*

Citation: Rawat, K., Chonhtham, N., and Bisht, M. S. 2022. Effect of drying processes on nutrients and bioactive components of edible bamboo (*Phyllostachys mannii* Gamble) shoots growing in Meghalaya, India. *Journal of Postharvest Technology*, **10**(1): 1-11.

INTRODUCTION

The principal role of food is to deliver sufficient nutrients (in quality and quantity) to meet elementary metabolic necessities of humans. Now-a-days consumption of vegetables by global populace increased rapidly due to awareness regarding presence of its several biologically active compounds with possible health promoting functions (Albuquerque, 2020; Samah and Ibhrajim, 2021). Several recent research has predicted wild underutilized plants as the noteworthy source of nutrients and bioactive components which is advantageous for human health (Peduruhewa et al., 2021).

In terms of food, bamboo is underutilized plant although is well known for its multipurpose usages and raw material for innumerable products. Worldwide, India has major acreage and the second largest genetic resources of bamboos (FAO, 2007). Young shoots of bamboos are used as food and medicinal source in Asian countries since generations. However, recent studies have identified the antioxidant, antimicrobial, hypolipidemic and cholesterol lowering properties of the bamboo shoots due to presence of several biologically active compounds (Wang et al., 2020; Curci et al., 2021). Out of several bamboo genera, shoots

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ISSN2348-4330

of *Phyllostachys* are regarded as superior quality vegetable and are used in various culinary purposes throughout the world. *Phyllostachys* is monopodial genus which encompasses of 55 species (Ohrnberger, 2002). In the present study, shoots of *Phyllostachys mannii* is taken for analysis. *P. mannii shoots* are recognised for its crunchy and sweet taste and has not been explored as nutrition source even though abundantly growing in North-East India. Shoots contain high moisture and thus are very perishable and susceptible to microbial decay and have short shelf life of 2-3 days. Thus, processing and preservation techniques are required to enhance shelf life and long-term consumption of shoots.

Drying is one of the most broadly used technique for long term preservation of vegetables that decreases moisture content, microbial activity, chemical reactions and expands the shelf life (Hamrouni-Sellami et al., 2013). Drying method is a good alternative to enhance shelf life of perishable bamboo shoots and also convenient for food processing industries. However, different drying methods may affect the product differently by altering mechanical, physical, biological, chemical and nutritional properties (Oliveira et al*.,* 2016). Oven drying, sun drying and freeze drying are the three commonly used methods employed in the present study.

An examination of literature shows that no detail studies have been carried out on the effect of these drying methods on the nutrient, minerals and bioactive components of shoots of edible bamboo. Thus, the objective of present work is to evaluate effect of three selected drying (freeze, oven and sun) processes on nutrients, amino acids, minerals and bioactive components of *Phyllostachys mannii* shoots and to select the best drying method in terms of retention of nutrients and bioactive components.

MATERIAL AND METHODS

Collection of plant material

The shoots of wildly grown *Phyllostachys mannii* were collected from Shillong, Meghalaya, India. The outer hard sheaths of shoots were peeled and inner part was retained for further processing.

Sample processing

Shoots were then processed through three different drying methods.

1) Freeze drying: Shoots were cut into cubes and initially frozen at -20ºC for 24 hrs in ultra low freezer. The frozen samples were then dried for 24 hrs in lyophilizer with 0.10 mbar vacuum pressure and -55ºC condenser temperature.

2) Oven drying: Shoots were cut into small cubes and placed a single layer in petriplates. These plates are then positioned in drying tray of hot air oven at 60ºC and dried for 24 hrs.

3) Sun drying: Shoots were cut into small cubes and a single layer of cut shoots were placed uniformly on a stainless-steel tray. The samples were dried under direct sunlight from 9:00 a.m. to 5:00 p.m. at temperature between 32-40ºC for 16 hrs in month of May. Samples were collected after each day and kept at ambient room temperature.

All form of dried shoots were then grounded into powder by using blender and kept in air tight bottles at room temperature till further use for analysis.

Estimation of nutrients

Protein, carbohydrate, starch, fat, ash and moisture were estimated by methods of AOAC (2000).

Vitamin C content was estimated by titrimetric method of Raghu et al. (2007). Vitamin E was determined by the method of Baker et al. (1980), using α, α'- Dipyridyl that forms a red coloured complex and gives absorbance maxima at 520 nm.

Minerals were analyzed by using Wavelength Dispersive X-ray Fluorescence (WDXRF) spectrometer (S8 TIGER, Bruker, Germany).

Free amino acids were estimated by using reversed phase ultra-high performance liquid chromatography (Agilent technologies, USA). Preparation of samples were carried out by technique of Lopez-Cervantes et al. (2006). 25 mg of dried powder was dissolved in borate buffer. The mixture was sonicated for 2 mins and centrifuged for 5 mins at 5000 r.p.m. The final extract was filtered and derivatized with O-Phthalaldehyde. Derivatized samples were examined chromatographically using C18 reverse phase column. The mobile phase was prepared by 10 mM each of disodium phosphate and sodium tetraborate with pH 8.35 and combination of methanol, acetonitrile and water in ratio of 40:40:20 v/v respectively. The rate of flow was maintained at 0.5 ml per min and detected by fluorescent detector having excitation and emission at 340 nm and 450 nm respectively.

Analysis of bioactive components

Bioactive components analysed include dietary fiber components, total phenols and total phytosterols.

Dietary fiber components *i.e*. Neutral detergent fiber (NDF), Acid detergent fiber (ADF), lignin, hemicellulose and cellulose were determined by method of Goering and Van Soest (1970).

NDF analysis involves gelatinization of sample using α-amylase followed by drying at 60ºC for 2 hrs. Dried sample was hydrolysed by sulphuric acid, followed by addition of dekalin and sodium sulphate and precipitated by heating. The final extract was ignited in the muffle furnace and the loss in weight determined as NDF.

ADF analysed by acid hydrolysis of dried sample in sulphuric acid, cetyl trimethyl ammonium bromide and dekalin. The precipitate formed was dried in oven for 8 hrs at 100ºC and the loss in weight determined as ADF.

For lignin analysis, the NDF and ADF residues were dissolved in sulphuric acid (72%) for 2 hrs. The residues were repetitively washed with hot water and acetone to eliminate acid and water respectively. The residue was ignited at 100ºC and lignin content was determined by loss in weight before and after ignition. Hemicellulose content was estimated by change in values of ADF and NDF. Cellulose was estimated by the variance in ADF and lignin content.

Total phenols content was estimated in accordance to Folin-Ciocalteau method using gallic acid as described by Singleton and Rossi (1965). 1g of sample was crushed in ethanol (80%) and centrifuged for 10 min at 4500 r.p.m. To 0.1 mL of supernatant 5 ml of Folin-Ciocalteau reagent (10%) was added and kept for 5 min. To this extract, 3.5 ml (1M) of Na_2CO_3 was added and incubated in water bath at 40°C for 1hr. Absorption was measured at 765 nm.

Total phytosterol content was estimated by using technique of Srivastava (1990). 1g of sample was homogenised in acetone-ethanol (1:1) mixture. The residue was then centrifuged, evaporated and chloroform was added. To 1 ml of final extract, acetic anhydride and H_2SO_4 (30:1) was added and left for 15-20 mins. Absorbance was taken at 680 nm using cholesterol as standard.

Statistical analysis

Experimental analysis was conducted in replicates of three. Data were subjected to ANOVA and Duncan's multiple range tests using PASW statistics software version 18.0 at significance level of $p<0.05$.

RESULTS AND DISCUSSION

Macronutrients

Macronutrients analyzed in freeze, oven and sun-dried shoots of *P. mannii* are presented in Table 1. With different drying processes, protein content ranged from 17.32 to 21.06 g/100g d.w. (dry weight). The maximum protein content was found in freeze dried shoots however, the content was not significantly different from oven dried. Previous studies in oven dried bamboo shoots revealed a range of protein from 5.1 to 25.80% (Christian et al., 2015). Carbohydrate content revealed significant ($p<0.05$) difference among dried shoots; maximum after freeze drying (14.27 g/100g d.w.) followed by sun (14.05 g/100g d.w.) and oven drying (9.90 g/100g d.w.). Previously, Karanja et al. (2016) reported carbohydrate content range from 17.3-23.6% in oven dried shoots of *Yushania alpina*. Starch content was significantly ($p<0.05$) higher in sun dried than oven dried shoots. But the content was not statistically different between sun and freeze drying methods. Fat content showed significant ($p<0.05$) variation among dried shoots with maximum content (8.40 g/100g d.w.) in oven dried shoots. Ash content ranged from 8.26-8.40 and showed no significant variation among different drying treatments. Moisture content in shoots ranged from 2.24-2.36%. after different drying treatments. All drying treatments were effective in lowering moisture content of shoots but the maximum reduction was after oven drying. Macronutrients like fat, starch, moisture and ash content in dried shoots of *P. mannii* falls in the range of other species of *Phyllostachys* reported previously (Zhang et al., 2011; Park and Jhon, 2013; Christian et al., 2015). Overall, results showed that freeze drying was better in retaining protein, carbohydrate, ash content in the shoots. Similarly, higher retention of nutrients with freeze drying has also been observed in other foods by Chan et al. (1997) and Arslan et al. (2010). Decrease in nutrients content after other two drying methods could be possibly due to high temperature during oven drying and continual exposure to air along with leaching effect during sun drying (Chan et al., 1997; Arslan et al., 2010).

Table 1: Macronutrients and vitamins content (dry weight) with different drying methods in *Phyllostachys mannii* shoots

Shoot type	**Macronutrients (g/100g)**						**Vitamins (mg/100g)**	
	Protein	Carbo-hydrate	Starch	Fat	Ash	Moisture	Vitamin C	Vitamin E
Freeze dried	21.06 ±2.33^{a}	14.27 ±0.08^{a}	10.84 ±1.12^{a}	4.53 ±0.02^{b}	8.35 ±0.20^{a}	2.29 ±0.04^{b}	40.85 ±2.46^{a}	8.17 ±0.14^{a}
Oven dried	18.01 ±1.49^{ab}	9.90 ±0.06^{c}	8.22 ±0.88^{b}	4.65 ±0.03^{a}	8.40 ±0.12^{a}	2.24 ±0.02^{b}	28.74 ±3.42^{c}	7.90 ±0.11^{b}
Sun dried	17.32 ±1.13^{b}	14.05 ±0.06^{b}	12.10 ±1.02^{a}	4.39 ±0.05^{c}	8.26 ±0.21^{a}	2.36 ±0.02^{a}	34.75 ±1.32^{b}	7.55 ±0.15^{c}

**Data are presented in mean values ± standard deviation (n=3).*
Values with different letters in each column indicate significant differences (p<0.05) among different drying treatments

Vitamins

Vitamin C and vitamin E contents of shoots after different drying processes are presented in Table 1. In present study, significantly higher vitamin C content was observed after freeze drying (40.85 mg/100g d.w.) followed by sun (34.75 mg/100g d.w.) and oven drying (28.74 mg/100g d.w.) method. Similarly, higher vitamin C content in freeze dried samples compared to sun and oven dried have also been reported in other plant foods (Sagar and Kumar, 2010; Sangsila et al., 2021). Lower retention of vitamin C after oven and sun drying may be due to high temperature and longer duration of drying (Jyaraman and Gupta, 1992). Vitamin C is highly thermo-sensitive and high temperature during oven and sun drying possibly led to greater losses. Vitamin E content ranged from 7.55 to 8.17 mg/100g d.w. with different drying treatments. Significantly higher content of vitamin E was observed with freeze drying followed with oven and sun drying treatment. Vitamin C and E are known to have antioxidant activity, defence and immune response and several other biological functions (Min et al., 2018; Alagawany et al., 2021).

Minerals

Minerals content in shoots processed with three drying treatments are shown in Table 2. Current study depicted the presence of 14 minerals elements with three dried forms. The minerals concentration was found in this sequence: K > P > Cl > S > Mg > Ca > S > Na > Zn > Fe > Mn > Cu > Mo > Ni. From results, insignificant difference in Si, Na and Zn content and significant ($p<0.05$) difference in Cl and Mo content was observed with three drying treatments. However, no significant ($p>0.05$) difference was seen with freeze and sun drying for K, Fe and Mn and with freeze and oven drying for P, Mg, Ca, S and Ni content. Overall, the content of P, Mg, Ca, S, Mo and Ni was found maximum with sun drying; K and Fe with freeze drying and Cl with oven drying. Sun dried shoots showed higher content of most of the minerals analyzed in the present study. The higher minerals content with sun drying is also reported in Capsicum varieties by Shokunbi et al. (2021). Minerals play a vital role in health promotion and prevention of several chronic and nutritional deficiency diseases (Gupta and Gupta, 2014).

Table 2: Macro and microminerals (mg/100g dry weight) with different drying methods in *Phyllostachys mannii* shoots

Type	Elements	Freeze dried	Oven dried	Sun dried
Macro minerals	K	6660 ± 40^{a}	5710 ± 60^{b}	6440 ± 110^{a}
	P	930 ± 20^{b}	930 ± 10^{b}	1100 ± 20^{a}
	Mg	230 ± 10^{b}	220 ± 10^{b}	290 ± 20^{a}
	Cl	850 ± 30^{b}	940 ± 20^{a}	760 ± 20^{c}
	Ca	110 ± 10^{b}	130 ± 10^{b}	180 ± 20^{a}
	Na	60 ± 10^{a}	60 ± 10^{a}	50 ± 10^{a}
	S	330 ± 10^{b}	330 ± 10^{b}	380 ± 10^{a}
	Si	70 ± 10^{a}	60 ± 10^{a}	70 ± 10^{a}
Micro minerals	Fe	9.1 ± 0.4^{a}	6.8 ± 0.3^{b}	8.7 ± 1.0^{a}
	Cu	2.6 ± 0.2^{a}	2.1 ± 0.3^{b}	2.5 ± 0.2^{ab}
	Zn	10 ± 0.0^{a}	10 ± 0.0^{a}	10 ± 0.0^{a}
	Mo	0.5 ± 0.0^{b}	0.1 ± 0.0^{c}	1.2 ± 0.1^{a}
	Mn	9.0 ± 1.0^{a}	5.4 ± 1.2^{b}	9.0 ± 1.5^{a}
	Ni	0.6 ± 0.0^{b}	0.6 ± 0.1^{b}	0.9 ± 0.0^{a}

**Data are presented in mean values ± standard deviation (n=3).*

Values with different letters in the same row indicate significant differences ($p<0.05$) among different drying treatments

Amino acids

Table 3 presents the content of twenty amino acids which were identified and quantified after different drying treatments in *P. mannii* shoots. It was noted that asparagine was the most abundant among all amino acids followed by tyrosine. Moreover, it was found that all three dried forms consist of almost all nine essential amino acids except tryptophan which was lacking in oven and sun dried shoots. This might be due to degradation of protein bound tryptophan during high temperature oven and sun drying processes (Shadung et al., 2012). Shoots dried from three different drying treatments showed variations in amino acids content. From Table 3 it was observed that amino acids like aspartic acid, glutamic acid, glycine, methionine and leucine contents showed significant ($p<0.05$) variation with freeze, oven and sun drying treatments. However, remaining amino acids showed no significant variation in their content with oven and sun drying. Histidine content was not statistically different among all three drying processes. Present study found that freeze dried samples compared to oven and sun dried samples had significantly higher content of all amino acids except ornithine. Overall results indicated less amino acid degradation after freeze drying. Similarly, high amino acids stability in low temperature freeze dried samples has also been reported in other foods (Shadung et al., 2012; Deng et al., 2015). Amino acids are indispensable as they regulate the directive of metabolic pathways and aids in treatment and management of numerous metabolic as well as communicable diseases (Wu, 2014).

Table 3: Free amino acid concentration (μg/mg dry weight) with different drying methods in *Phyllostachys mannii* shoots

Free amino acid	**Freeze dried**	**Oven dried**	**Sun dried**
Aspartic acid	16.28 ± 1.10^{a}	13.97 ± 0.72^{b}	10.43 ± 1.46^{c}
Glutamic acid	10.81 ± 0.79^{a}	5.38 ± 0.68^{c}	8.60 ± 0.83^{b}
Asparagine	111.04 ± 9.59^{a}	87.83 ± 3.42^{b}	84.06 ± 3.64^{b}
Serine	9.57 ± 0.85^{a}	5.71 ± 0.36^{b}	4.71 ± 0.72^{b}
Glutamine	5.48 ± 0.40^{a}	2.58 ± 0.88^{b}	2.17 ± 0.63^{b}
Histidine	4.21 ± 0.29^{a}	3.60 ± 0.43^{a}	4.12 ± 0.60^{a}
Glycine	3.62 ± 0.00^{a}	3.02 ± 0.12^{b}	2.38 ± 0.24^{c}
Threonine	8.91 ± 0.51^{a}	7.04 ± 0.42^{b}	7.02 ± 0.34^{b}
Arginine	14.70 ± 0.68^{a}	11.81 ± 0.48^{b}	11.63 ± 0.64^{b}
Alanine	10.22 ± 1.05^{a}	6.84 ± 0.82^{b}	7.52 ± 0.48^{b}
Taurine	9.77 ± 0.14^{a}	7.09 ± 1.28^{b}	5.89 ± 1.02^{b}
Tyrosine	41.21 ± 3.21^{a}	32.47 ± 1.47^{b}	36.47 ± 1.62^{b}
Valine	21.11 ± 1.40^{a}	10.59 ± 1.86^{b}	10.12 ± 2.40^{b}
Methionine	2.39 ± 0.10^{a}	1.17 ± 0.08^{c}	1.63 ± 0.21^{b}
Tryptophan	8.29 ± 0.12^{a}	ND	ND
Phenylalanine	7.54 ± 0.47^{a}	6.14 ± 0.33^{b}	6.39 ± 0.31^{b}
Isoleucine	7.80 ± 0.30^{a}	4.98 ± 0.31^{b}	5.38 ± 0.34^{b}
Leucine	12.84 ± 0.86^{a}	11.18 ± 0.24^{b}	9.09 ± 0.32^{c}
Lysine	3.96 ± 0.14^{a}	2.77 ± 0.00^{b}	2.81 ± 0.15^{b}
Ornithine	1.05 ± 0.10^{b}	1.92 ± 0.12^{a}	2.02 ± 0.16^{a}

*ND -not detected, *Data are presented in mean values ± standard deviation (n=3).*

Values with different letters in the same row indicate significant differences ($p<0.05$) among drying treatments

Bioactive components

Total phenolic and phytosterols content analyzed with different drying treatments are presented in Table 4. Total phenolic content ranged from 1315.50-1918.90 mg/100g d.w. being maximum with freeze drying. However, the content was insignificant between freeze and sun drying. Similar findings of higher content of phenols with freeze drying compared to sun and oven drying has also been reported in other foods (Gao et al. 2012; Sangsila et al. 2021). This might be accounted to low temperature freeze drying process inactivates enzymes responsible for degradation of phenolic compounds. Phytosterol content ranged from 98.90-265.49 mg/100g d.w. Phytosterols content varied significantly ($p<0.05$) with three drying treatments with significantly higher levels with oven drying followed by sun and freeze drying. In literature, no major studies were reported on the effect of drying methods on phytosterols for comparison. Phenol and phytosterols are the bioactive compounds that are known to promote wellbeing and prevent the risk of several ailments in humans (Rashmi and Negi, 2020; Shao et al, 2021).

Table 4: Content of bioactive components with different drying methods in *Phyllostachys mannii* shoots

Shoots type	Total phenols (mg/100g)	Total phytosterols (mg/100g)	Dietary fiber and its components (g/100g)				
			NDF	ADF	Lignin	Cellulose	Hemicellulose
Freeze dried	1918.90	98.90	67.70	6.52	1.04	5.48	61.18
	±50.70^{a}	±2.48^{c}	±2.45^{a}	±0.98^{a}	±0.04^{b}	±0.18^{c}	±4.21^{a}
Oven dried	1315.50	265.49	53.70	7.43	1.40	6.03	46.27
	±54.82^{b}	±3.16^{a}	±3.17^{b}	±1.06^{a}	±0.07^{a}	±0.14^{b}	±3.48^{b}
Sun dried	1849.81	230.48	65.80	8.50	1.34	7.16	57.30
	±51.80^{a}	±3.88^{b}	±2.64^{a}	±1.42^{a}	±0.07^{a}	±0.26^{a}	±3.14^{a}

**Data are presented in mean values ± standard deviation (n=3).*
Values with different letters in each column indicate significant differences (p<0.05) among different drying treatments

Dietary fibers components analyzed in three dried samples are presented in Table 4. NDF and hemicellulose content was maximum with freeze drying but the contents were not statistically significant with freeze and sun drying processes. ADF content showed non-significant ($p>0.05$) difference among three drying treatments. Lignin content was higher in oven dried shoots and least in freeze dried shoots with no significant variation between oven and sun dried samples. Higher content of lignin with oven drying was due to non-enzymatic browning at higher temperature which increases the lignification. Cellulose content showed significant difference among drying treatments; being maximum in sun dried followed by oven and freeze dried shoots. No major work has been published in literature on the studies of effect of different drying methods on dietary fiber components. Dietary fiber is associated with prevention of various chronic diseases, including cardiovascular diseases, cancer and type 2 diabetes, and several types of cancer (Veronese et al., 2018).

CONCLUSION

This present research highlighted the nutritional, mineral, amino acids and bioactive components of *P. mannii* shoots as affected by three (freeze, oven and sun) drying processes. Besides nutrition, 20 amino acids and 14 minerals were identified in the dried shoot samples. Of these, amino acid (asparagine) and mineral (potassium) were the most abundant. These nutrients are affected differently with three methods. Coupled with longer shelf life, freeze drying was the most efficient method in retaining most of nutrients (carbohydrate, protein, amino acids, vitamin C). This method also maintained high content of total phenols. Moreover, sun-drying was better method concerning the mineral contents of the shoots. Dried shoots powdered have prodigious potential to be used for supplementation of minerals, essential amino acids, fiber and sterols in biopharmaceuticals and food fortification. Present study is also valuable in guiding food processing industries as drying methods are valuable in minimizing the post-harvest decaying and nutrient loss of bamboo shoots.

ACKNOWLEDGEMENTS

The authors would like to acknowledge University Grant Commission (F7- 151/2007) and Ministry of Food Processing Industries (18/MFPI/R&D/2010), Govt. of India for providing financial assistance.

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