Theme 3.2. Food and Pharmaceuticals

Quantitative assessment of silicon in fresh and processed bamboo shoots and its potential as functional element in food, nutraceuticals and cosmeceuticals

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Abstract

Bamboo, belonging to the family Poaceae, is considered a valuable plant due to its numerous industrial and medicinal uses and is also known to be a distinctive silicon accumulator. Silicon has not been largely documented as an essential trace element but over the past few decades, several biochemical and clinical studies have demonstrated the advantageous effects of silicon on the human health. Though biological attention in this element has increased, data of silicon content in majority of the food plants still need to be determined. In this study, silicon content was estimated by Wavelength Dispersive X-Ray Florescence (WDXRF) spectrometer technique in the fresh and processed (soaked, boiled, fermented) shoots at different storage stages (3 – 12 months) at 4ºC of five bamboo species viz. *Bambusa balcooa, Dendrocalamus giganteus, D. hamiltonii, D. membranaceus* and *Phyllostachys mannii* that are grown in different geographical regions of India. Results revealed the highest silicon content was found in *D. hamiltonii* (190 mg/100g d.w.) and least in *P. mannii* (70 mg/100g d.w.). Silicon content was reduced by 6-33% with all processing except soaking in *D. giganteus* and *P. mannii* and by 25-71% after 3-12 months storage. The highest amount of Si was retained in shoots of *D. giganteus* after processing and storage. Bamboo shoots were also found to be silicon-rich food that can offer significant prospects for Si dietary supplementation. Moreover, the abundance of silicon in bamboo shoots can be promising to be used as food supplement as well as for nutraceutical and cosmetic industries.

Introduction

The role of minerals in medicine is gradually becoming more prominent nowadays. Trace elements are presently being studied to define their dietary significance and influence on health. For a long time, silicon (Si) was not largely documented as an essential trace element and believed to be an inactive material. The majority of people recognize silicon and its compounds as a class of substance used in manufacture of glass and electronic devices, such as transistors, solar cells, rectifiers and microchips as well as an ingredient in soaps, adhesives, lubricants, polishing agents and medical implants (Kanda 1991; Jugdaohsingh 2007; Price et al. 2013). However, over the past few decades several biochemical and clinical studies have demonstrated the advantageous effects of silicon and documented it as one of the most indispensable trace element in human metabolism (Martin 2013; Cofrades et al. 2016; Arora and Arora 2017). Silicon bound to glycosaminoglycan is a significant constituent of the extracellular matrix and also stimulates the crosslinking and synthesis of protein such as elastin and collagen that gives the strength, integrity and flexibility to the connective tissues of skin, bones, nails, hairs and arteries (Martin 2013). It is also considered as an anti-aging nutrient and also responsible for maintaining bone volume and density in osteoporosis patients (Jugdaohsingh 2007). Silicon is in consideration for promotion to the rank of a “plant beneficial substance” by the Association of American Plant Food Control Officials (AAPFCO 2006).

Silicon (Si) is a chemical element, tetravalent metalloid with an atomic number of 14 and atomic weight of 28. It is semiconductor and its crystalline form is piezo resistive, thus extensively used in micro pressure transducers and computer electronics. Silicon is the second most plentiful element after oxygen in the Earth's crust (Exley 1998). In nature, it is rarely present in elemental form as it bonds strongly with oxygen and forms insoluble silica (SiO_2) and silicates compounds. These are highly stable structures and have several industrial applications comprising electronics, abrasives and construction. These silica compounds have poor water solubility and biological availability and thus are not useful dietary sources (Peters et al. 1999; Martin 2013; Price et al. 2013). On the contrary, chemical and biological weathering releases and dissolves silicon in water from geological formations and results in formation of several water soluble forms denoted together as silicic acid (ortho-, meta-, di-, and tri-silicates) that are more biologically available (Price et al. 2013).

Silicon in plants

Silicon is extensively present in its inorganic form SiO_2 in the soil which can be absorbed by plants and transform inorganic silica into organic form i.e. orthosilicic or monosilicic acid $Si(OH)_4$, which is taken up by the plant roots through transpiration stream and making it bioavailable for humans to absorb (Epstein 1999, Jugdaohsingh et al. 2002; Li et al. 2014). In plants, silica gets bonded with water molecules and is usually deposited in microscopic bodies named as phytoliths or opal phytolith which is present in the the cell wall, lumen and intercellular space during plant growth (Kaufman et al. 1999; Tripathi et al. 2012). These phytoliths are present in several plants, particularly abundant in members of family poaceae, e.g., bamboo, rice (Li et al. 2014; Tripathi et al. 2017). Silicon improves plant cell wall strength and structural integrity, plant vigour, biomass, yield and plants resistance to abiotic and biotic stresses (Epstein 1999; Tripathi et al. 2017). The plant-based products have more silicon than animal based products (Pennington 1991), common plant based foods with high silicon content are cereals (rice, barley, oats) and some vegetables (beans, spinach and root vegetables (Jugadohsingh 2007). Though biological attention in this element has increased, data of silicon content in majority of the food plants still need to be determined.

Bamboo, a distinctive phytolith-accumulator belongs to family Poaceae, is predominantly distributed in tropical and subtropical regions of the world (Li et al. 2014). Bamboo is the richest known source of natural silica, containing over 70% organic silica, which is more than ten times the level found in the widely used horsetail plant (*Equisetum*) (5% to 7% silica). Different parts of bamboos are used in ancient Chinese, Indian Ayurveda, Tibetan and various traditional system of medicine for a number of ailments (Nirmala and Bisht 2017). Tabasheer or banslochan or bamboo-manna, mainly consist of pure silica, obtained from bamboo internodes is a part of the pharmacology of the traditional Ayurvedic and Unani medicine in the Indian subcontinent. It acts as stimulant, astringent, febrifuge, tonic with antispasmodic and aphrodisiac properties and main ingredient in Sitopaladi Ayurveda medicine (Nirmala and Bisht 2017). Menghao et al (2012) investigated the effect of silica extract of *Phyllostachys edulis* leaves on bone loss in ovariectomized rats and observed that silica supplementation increased significantly the femoral and lumbar bone mass density.

Bamboo shoots, the young edible buds of bamboo, are gaining ample cognizance globally due to occurrence of various nutrients and active phytochemicals which are proven to have biological activities (Bajwa et al. 2016; Rawat et al. 2016; Nirmala and Bisht 2017). Fresh shoots are the most delicious and nutritious part of the bamboo. However, consumers preferred shoots in pickled, fermented, canned, roasted, boiled and salted forms. It is also widely incorporated in numerous indigenous and contemporary dishes in different parts of the world (Rawat et al. 2016). Analysis of some macro and micromineral elements has been worked out in some bamboo genera; *Bambusa*, *Chimonabamusa*, *Dendrocalamus*, *Pseudosasa* and *Phyllostachys* (Waikhom et al. 2013; Christian et al. 2015; Park and Jhon 2013; Saini et al. 2017). Bamboos are remarkably good silica accumulators but silicon content found in fresh and processed shoots of different bamboo species are not very well known. In this study, an advanced technique the wavelength dispersion X-ray fluorescence spectrometry (WDXRF) was used for quantitative assessment of silicon of fresh and processed shoots of five bamboo species growing in Indian subcontinent.

Material and methods

Sample collection

Young shoots of five bamboo species viz. *Bambusa balcooa* Roxb, *Dendrocalamus giganteus* Munro, *Dendrocalamus hamiltonii* Nees & Arn. Ex Munro, *Dendrocalamus membranaceus* Munro and *Phyllostachys mannii* Gamble were analyzed. The shoots of selected species were harvested during the months of May to September for three consecutive years (2014-2016) from upper Shillong, Meghalaya (25.5º N, 91.89º E); Imphal, Manipur (24.66° N, 93.9° E); Forest Research Institute, Dehradun, Uttarakhand (30.3° N, 78.0° E) and Bambusetum of P.N. Mehra Botanical garden, Chandigarh (30.5° N, 76.5° E). In laboratory, the hard outer culm sheaths of harvested shoots were removed or peeled off by hand or knife and the inedible hard basal portion of shoot was discarded while the remaining edible part was washed and cleaned under tap water.

Processing of samples

Processing methods used in current analysis were boiling, soaking, fermentation, storage in water and brine for three, six and twelve months.

Boiling and soaking: 200g of shoot samples were cut into cubes and boiled for 20 minutes and soaked for 12 hours in water. The duration of treatments were selected as a result of preliminary works (Rawat et al. 2016).

Fermentation: 200g of shoots were chopped into thin slices and then squeezed compactly in clean muslin cloth. These were then put into small jars and kept under pressure by putting weight above samples and left for 15-25 days at room temperature 25 ± 2°C. Shoots were hand pressed at regular intervals for removal of exudates coming out from the shoots during the process. The particular aroma and softness of shoot tissue confirmed the completion of fermentation.

Refrigerated storage: 400g of shoots were boiled and packaged in autoclaved glass bottles with pre-sterilized water and 5% brine (w/v). The containers were then covered tightly and stored up to twelve months in refrigerator at 4°C.

Quantitative analysis of silicon

Sample preparation

All the samples were kept in deep freezer for 24 hours and then the frozen samples were dried in Lyophilizer (LYOQUEST 55, Skadi, Europe) with 0.10 mbar vacuum pressure and -55 °C condenser temperature for 24 hrs. Lyophilized samples were homogenized to fine powder with grinder to attain a particle size less than 50 µm. Then a pellet (34 x 4 mm diameter and thickness) was made by using hydraulic pressure (Insmart, Hyderabad) approximate 15 tons with a standing time of 10 seconds.

Sample analysis by WDXRF

Elemental testing was performed by using a commercial WD-XRF spectrometer S8 TIGER (Bruker, Germany) which was controlled by software (Quant Express). The Equipment was characterized with rhodium X-ray tube; 6 analyzer crystals (LiF200, LiF220, PET, XS55, XSN, XSC) and eight primary beam filters. The scintillation counter for heavy elements and gas proportional counter for lighter elements were implied. Maximum current and power directed were 170 mA and 4 kW respectively. Analysis of individual sample was carried out for 20 min.

Results

SILICON CONTENT OF FRESH SHOOTS

Silicon is documented as one of the valuable element in plants and human beings due to its multifarious role. Since bamboo shoots are getting popular globally as a healthy food, the silicon content has been analysed in shoots of five bamboo species in the present study. The silicon content of fresh shoots of five investigated species *viz. Bambusa balcooa*, *Dendrocalamus giganteus*, *D. hamiltonii*, *D. membranaceus* and *Phyllostachys mannii* was ranging from 70-190 mg/100g dry weight (d.w.) The maximum amount of silicon (190 mg/100g d.w.) was in *D. hamiltonii* species, followed by *D. membranaceus* and *B. balcooa* (150 mg/100g d.w.) while *P. mannii* exhibited the least amount (70 mg/100g d.w.) (Fig 1).

SILICON CONTENT OF PROCESSED SHOOTS

Silicon content of *D. giganteus* and *P. mannii* was unaffected by soaking while a reduction of 6-27% was observed in the remaining species with highest reduction in *B. balcooa* ad least in *D. giganteus* (Fig 1). Compared to soaking, boiling caused slightly more decline of Si (8-33%) with highest and least reduction in *B. balcooa* and *D. giganteus* shoots respectively. Moreover, fermentation caused a 6-26% decline in Si, with maximum reduction in *D. hamiltonii* and minimum in case of *D. membranaceus* (Fig 1).

During the refrigerated storage of shoots in water and 5% brine, there is a general trend of decline in Si content by 25-57% after 3 months and 33-60% after 6 months in the shoots of five bamboo species (Fig 2). After 12 months, Si content decreased by 33-60% in water preserved shoots and 50-71% in brine preserved shoots of five bamboo species. The retention of Si was more in shoots preserved in the water than brine. Among the all investigated species, Si was retained maximum in *D. giganteus* shoots in both water and brine storage (Fig 2).

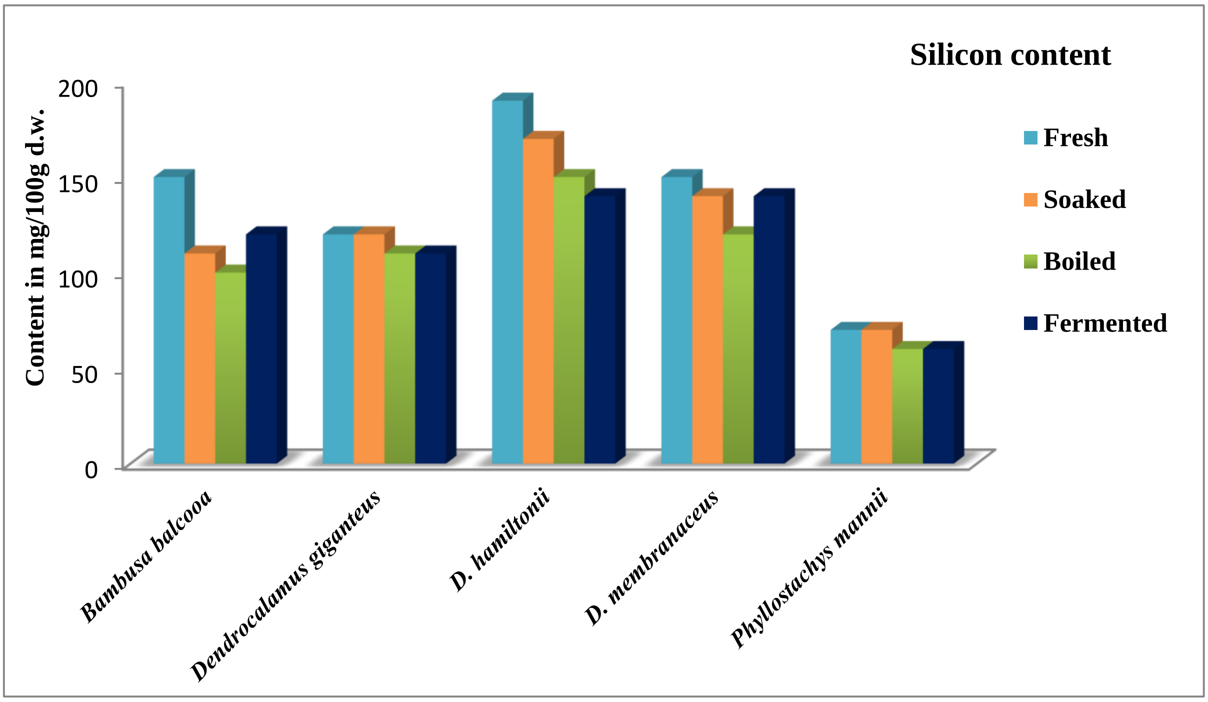

Fig.1. Silicon content (mg/100g dry weight) in fresh shoots of five bamboo species and changes in its content with different processing treatments

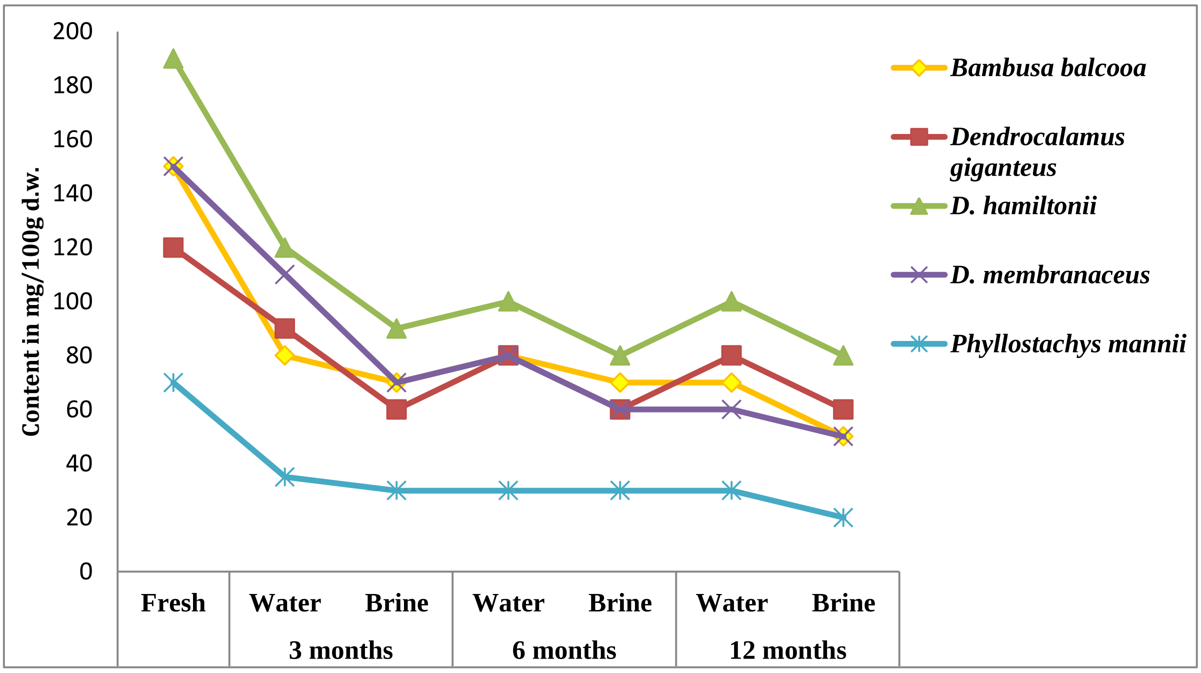

Fig.2. Changes in silicon content (mg/100g dry weight) at three stages (3, 6 and 12 months) of storage of shoots in water and brine of five bamboo species

Discussion

Silicon is reflected as a significant trace mineral that supports in formation of healthy and strong skeleton, prevention of osteoporosis, Alzheimer's, and cardiovascular disease and gives strength, integrity and flexibility to the connective tissues of skin, bones, nails, hairs and arteries (Martin 2013; Nielsen 2014; Price et al. 2013). Average daily dietary intake of silicon is 20-50 mg in western countries (Jugdaohsingh 2007) while it is higher (140-200 mg/day) in China and India where plant centred foods form a greater part of the nutrition (Chen et al. 1994; Anasuya et al. 1996). Lethal dose 50 (oral) for silicon is 3160 mg/kg. These water soluble forms are absorbed in the human gastrointestinal tract, with surplus amount removed within 4 to 8 hours ingestion by the kidneys (Jugdaosingh 2007). Therefore, it is unlikely for silicon to accumulate in extreme amounts in healthy people (Price et al. 2013). In this work, Si content of fresh shoots ranged from 70-190 mg/100g d.w. of five analysed bamboo species. Table 1 summarizes the silicon content of bamboo shoots and some commonly consumed foods. Cereals are also good source of silicon while meat and fish are poor dietary source of silicon (Robberecht et al. 2009). Bamboo shoots were found have higher silicon content in comparison to other commonly consumed vegetables (Table 1). Our reported range of silicon in bamboo shoots is relatively higher (70-190 mg/100g dry weight) to previous reported range (3.52-4.45 mg/100g wet weight) of Si in *Phyllostachys pubescens* and *Sinoarundinaria nigra* by Park and Jhon (2013). But, the difference in values may be due to environmental factor, genetic variability of bamboo and methods used in the studies. The Si content of food changes depending on the food variety, food processing and food additives. In this work, all the processing and storage treatments resulted in decrease in Si content except soaking. Decline in Si content after boiling has also been observed in former study carried out by Park and Jhon (2013) in *Phyllostachys pubescens* and *Sinoarundinaria nigra* shoots. This kind of reduction in silicon might be due to solubility of plant based amorphous silicon with processing and storage (Dove et al. 2008). Literature data reveals that no major work has been carried out in silicon content of fresh and processed bamboo shoots and also reports in the effect of food processing is very limited. Moreover, elemental content of the soil, type of food product, country of origin of food, species, preparation and storage circumstances diverge considerably that comparison of silicon levels are not easy to define.

Table. 1. Total silicon content in bamboo shoots and some commonly consumed foods

S. No.	Food	Silicon content	References
1	Bamboo shoots	70-190 mg/100g dry weight	Present study
2	Bamboo shoots *Phyllostachys praecox* *Sinoarundinaria nigra*	 3.52 mg/100g wet weight 4.45 mg/100g wet weight	Park and Jhon 2013
3	Beans	55.77 mg/kg wet weight	Robberecht et al. 2008
4	Buckwheat	1980 ug/kg dry weight	Dejneka and Lukasiak 2003
5	Fish	1.77-84.19 mg/kg wet weight	Robberecht et al. 2009
6	Meat (Beef, Chicken, Pork)	0.96-1.30 mg/kg wet weight	Robberecht et al. 2009
7	Oat flakes	188 mg/kg wet weight	Robberecht et al. 2008
8	Potatoes	1.39-3.80 mg/kg wet weight	Robberecht et al. 2008
9	Rice	161.50 mg/kg wet weight	Robberecht et al. 2009
10	Spinach	17.82 mg/kg wet weight	Robberecht et al. 2008

In several industrial food preparations, powdered silica is used to reduce foaming, caking of powders and for liquids clarification. In this study, bamboo shoots are found to be silicon rich food and it can offer significant prospects for Si dietary supplementation. Moreover, bamboo shoots in fresh, boiled, fermented extracts, paste and dried powdered form can be used to fortify foods which are naturally lacking or low in Si levels such as meat products. Nowadays, there are various silica supplements offered in market either in tablet or solution form, one such commercially available liquid Si nutritional supplement is Monomethylsilanetriol (MMST) or CH_3-Si-$(OH)_3$ (Aguilar et al. 2009). However, plants based foods provide more silicon than any other source and are more suitable for human consumption due to its higher bioavailability (Tripathi et al. 2017). The Si biofortified foods can be valuable co-adjuvant in the prevention and management of several diseases and maintenance of overall health and wellness.

Silicon as an ingredient in nutraceuticals

Nowadays, there is growing attention in functional foods and Nutraceuticals thus; there are novel and promising research zones in field of life sciences. Nutraceutical, a term arises from “nutrition” and “pharmaceutical”, is a fortified product sequestered or purified from foods or usually consists of a concentrated bioactive ingredient derived from food that are usually sold in a medicinal formula. They have defensive role against chronic ailments or have physiological effects. In the recent years, numerous in vitro and in vivo studies have shown several significant benefits of Silicon in human health which are compiled in Table 2. Martinez et al (2015) and Ghanaati et al (2010) have found that silicon stimulates osteoblast differentiation, bone formation, bone regeneration and vasculogenesis, and may also assistance in drug delivery. Si inclusion to meat and pork strongly counterbalanced the negative influence of high-cholesterol ingestion by reducing glucose and triglycerides digestion and absorption resulting to an active hypotriglyceridaemic, hypoglycaemic, hypocholesterolemic and anti-oxidative dietary ingredient in aged rats (Garcimartin et al. 2014, 2015, 2017). At present, the meat industry is introducing modifications in meat and meat by-products by allowing the incorporation of active components or functional ingredient such as silicon with potential effects to generate "functional" products (Garcimartin et al. 2015).

Silicon as an ingredient in cosmeceuticals

Cosmeceuticals are products containing biologically active ingredients extracted and purified from natural sources (botanicals, herbal extracts, or animals) proclaiming to offer a pharmacological benefits (Antonopoulou et al. 2016). A number of plants have been utilized by the industry to generate novel cosmeceutical formulations with specific purposes such as anti-ageing, anti-wrinkling, anti-oxidant, anti-inflammatory, anti-allergy and photoprotective activity (Antonopoulou et al. 2016; Dorni et al. 2017). Silica and silicates are such ingredients which are widely used as a viscosity control agents and as an excipient in facial scrub, shampoos, toothpaste, hand and nail creams and several cosmetics (Jugdaohsingh 2007). The shoot and leaves of bamboo, *Arundinaria gigantea* and its fermentation extract used in anti-ageing skincare formulations are believed to show cellular action through proteasome to repair ageing signs (Lu and Liu 2003). Bamboo shoots are found to be a rich source of silicon which is responsible for strength, integrity and flexibility of the connective tissues of skin, bones, nails, hairs thus an anti-aging nutrient. Additionally, shoots are phenols, sterols and fiber rich and the characteristic compounds present are protocatechuic acid, p-Hydroxybenzoic acid, catechin, caffeic acid, chlorogenic acid, syringic acid, p-Coumaric acid, ferulic acid, b-sitosterol, campesterol, stigmasterol, ergosterol and tocopherols (Park and Jhon 2010; Nirmala et al. 2014). These compounds have antioxidants, anti-inflammatory, antiallergy, antimicrobial, anti-aging properties and thus shoots have great prospective to be used as an active ingredient in cosmeceuticals.

Table 2. Potential of Silicon as a nutraceutical element

S. No	Potential benefits	References
1.	Anti-inflammatory	Nielsen 2014
2.	Anti-aging	Jugdaohsingh 2007
3.	Antidiabetic	Martin 2013
4.	Anti-osteoporosis	Menghao et al. 2012
5.	Antioxidant	Garcimartin et al. 2015
6	Bone mineral density	Arora and Arora 2017
7.	Bone regeneration property	Choi and Kim 2014; Arora and Arora 2017
8.	Hypo-triglyceridaemic	Garcimartin et al. 2017
9.	Hypo-cholesterolemic	Garcimartin et al. 2014, 2015
10.	Hypo-glycaemic	Garcimartin et al. 2017
11.	Neuroprotective	Garcimartin et al. 2014

Table 3. Commercially available nutraceuticals products and food supplements of bamboo Silica

S. No	Part used	Product Name	Company	Country
1.	Tabashir exudate	Bamboo extract silica	British supplements	United Kingdom
2.	Tabashir exudate	Bamboo silica (Silice de Bambou)	Enerex botanicals Ltd	Columbia
3.	Tabashir exudate	Bamboo Tabashir powder	Ancient Purity Ltd	England
4.	Tabashir exudate	Fenioux Bambou Tabashir	Natural Health Herbalist	Spain
5.	Tabashir exudate	Herbal Bamboo extract	Ayurish	India
6.	Bamboo exudates	High potency silica	Nature’s best	United kingdom
7.	Tabashir exudate	Lambert Silica capsules	Lamberts Healthcare Ltd	United Kingdom
8.	Culms	Solaray bamboo supplement	Nutraceutical corp	USA

Conclusions

Minerals are the naturally existing elements in foods which are playing a vital role in medicine. Silicon is one such important trace mineral which has recently been considered as important for several potential health benefits. The food and nutraceuticals industry is currently demanding all natural constituents derived from the edible plants. Bamboo shoots are widely known edible food for its nutritive and functional properties. Analysis of silicon content in the fresh and processed shoots of investigated bamboo species revealed highest silicon content in *D. hamiltonii* and least in *P. mannii*. Silicon content was reduced with processing and storage and the highest amount was retained in *D. giganteus*. These species are growing in different zones of India and can be promoted as a natural source of silicon so that it can be used for dietary supplementation. The prominence of silicon in bamboo shoots can be promising as a natural functional ingredient or additive in foods which are lacking or have low silicon levels as well as an adjunct in the nutraceuticals, cosmeceuticals and food industries. However, more research is required to explore silica in other species of bamboos and its bioavailability in the humans.

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