Advances in Bamboo Science 7 (2024) 100078

Contents lists available at ScienceDirect

Advances in Bamboo Science

journal homepage: www.journals.elsevier.com/advances-in-bamboo-science

Review

Tradition meets technology: An overview of fermented bamboo shoots

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ARTICLE INFO

Keywords:
Bamboo
Bamboo shoots
Fermentation
Lactic acid bacteria
Nutrition

ABSTRACT

This review article explores the multifaceted significance of fermented bamboo shoots, a culinary tradition deeply rooted in the practices of local tribes in Northeastern India. The therapeutic properties of fermented bamboo shoots span anti-aging, anticancer, antioxidant, cardioprotective, and weight loss benefits, positioning them as valuable functional foods enriched with probiotics. Northeast India, encompassing the states of Assam, Arunachal Pradesh, Nagaland, Meghalaya, Mizoram, Sikkim, Manipur, and Tripura, serves as a hub for the cultivation and consumption of fermented bamboo shoot-based products. The unique microbial ecosystem associated with bamboo shoots contributes to the synthesis of diverse health-promoting compounds, with rich concentrations of glycosides and flavones. Microorganisms, including *Lactobacillus* species, *Bacillus* species, *Candida* species, and *Saccharomyces cerevisiae* play a pivotal role in the fermentation process, contributing to the distinct characteristics of these products. The active involvement of tribal communities, constituting 75 % of the regional population, underscores the cultural and traditional significance of this culinary practice. The review also delineates an array of fermented bamboo shoot-based products offerings, such as *ekung*, *heccha*, *eup*, *mesu*, *lung-siej*, *soibum*, *soidon*, *soijim*, and *hirring*, reflecting the rich culinary diversity arising from this traditional practice. Beyond their cultural importance, these products hold substantial industrial and economic value, and are integral to the livelihoods of local communities in Northeastern India. In summary, fermented bamboo shoots have emerged as a complex resource intertwining cultural heritage, health benefits, and economic dimensions within the unique context of Northeastern Indian communities.

1. Introduction

Botanically placed in the *Poaceae* family and the *Bambusoideae* subfamily, bamboo comprises more than 1642 species distributed globally, with a significant presence in Asia (Pattarathitiwat et al., 2021). Members of the *Bambusoideae* subfamily grow in varied climates and are indigenous to all the continents besides Europe and Antarctica (Srivastava et al., 2019). It is the fastest-growing persistent grass and considered as one of the significant groups of plants worldwide. Due to their extensive diversity, bamboo populations can be geographically categorized into three specific zones: the American zone, the Asian Pacific zone, and the African zone (Mustafa et al., 2021). These woody-stemmed grasses are known for their rapid growth, high biomass production, and quick yield, along with the possibility of efficient utilization within a few years. This has led to the recognition of bamboo as a 'Green Gold' (Goyal and Sen, 2016). Bamboo exhibits rapid growth rates of up to 1.2 m per day. It features a system of connected underground rhizomes and above-ground bamboo shoots, facilitating the transport and sharing of nutrients (Zhang et al., 2021). Bamboo has many uses and is an indispensable product for the inhabitants of Asian countries (Basumatary et al., 2018). It is used extensively in making decorative items, such as construction material, by the paper and pulp industries, and in cooking (Goyal and Sen, 2016). The versatility of bamboo makes it convenient to fit in 10 out of the 17 UN Sustainable Development Goals (SDGs) i.e. Goal-1 (No poverty), Goal-2 (Zero hunger), Goal-3 (Good health and well-being), Goal-6 (Clean water and

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https://doi.org/10.1016/j.bamboo.2024.100078
Received 31 December 2023; Received in revised form 7 April 2024; Accepted 8 April 2024
Available online 8 April 2024

sanitation), Goal-7 (Affordable and clean energy), Goal-8 (Decent work and economic growth), Goal-11 (Sustainable cities and communities), Goal-12 (Responsible consumption and production), Goal-13 (Climate action), and Goal-15 (Life on land) (https://www.bambooinfo.in/more/bamboo-sustainable-development-goals.asp. Accessed on 27.12.2023).

Bamboo shoots, characterized as young and developing culms emerging from the nodes of bamboo pseudo-rhizomes, are commonly regarded as a highly desirable vegetable due to their sweet flavour, crisp and crunchy texture, and exceptional nutritional value (Li et al., 2022). The fibre-rich shoots are a source of minerals and proteins and are low in cholesterol and fats (Basumatary et al. 2017) and thus used in culinary preparation especially in Asian countries. Bamboo shoots are laden with poisonous taxiphyllin (cyanogenic glycoside), but this can be eliminated through appropriate processing before consumption (Acharya et al., 2023). Bamboo shoots can be eaten either fresh (in their initial growing season), dried, or fermented (during the off season). Diverse ethnic groups and their different food habits have resulted in distinctive and different foods and beverages around the globe (Kalita et al., 2023). Fermented food has been an integral part of the human diet since ancient times (Narzary et al., 2021). The use of microbes during fermentation not only helps increase the shelf-life of the food but also enhances taste and flavour (Narzary et al., 2021). Bamboo shoots are fermented differently by different ethnic groups in Asia.

The objectives of this review are to examine and categorize a diverse range of fermented bamboo shoot-based products, including, *ekung*, *heccha*, *eup*, *hirring*, *lung-siej*, *mesu*, *soibum*, *soidon*, and *soijim*, thereby providing a comprehensive overview of the culinary diversity stemming from the traditional practice of fermenting bamboo shoots. This review emphasizes the different fermented bamboo shoot products along with the country of origin, providing an insight into the nature of the product, the bamboo species used along with other ingredients (if any), the fermentation process, microorganisms used and their nutritional values.

2. Methodology

This review of the fermented bamboo shoots products worldwide was performed in accordance with Narzary et al. (2023, 2024) (Fig. 1).

2.1. Information sources and search strategy

Original or review articles were systematically queried within diverse bibliographic databases such as PubMed, Scopus, and Google Scholar, employing a range of specified keywords such as Fermented, bamboo shoots, bamboo, bamboo products in various combinations.

2.2. Inclusion criteria

Documents published between 1st January 2010 and 1st December 2023, were selected for their relevance to fermented bamboo shoot products. Only full-text articles identified as meeting the search parameters were considered.

2.3. Exclusion criteria

Only articles published in english were considered. Articles dealing with non-fermented bamboo shoot products were excluded

3. Fermented bamboo shoots

Fermented bamboo shoots generate a niche for numerous microorganisms, offering various advantages. They have various therapeutic properties including anti-aging, anticancer, antioxidant, cardioprotective and weight loss benefits due to the presence of different glycosides and flavones. Furthermore, they are recognized as crucial functional foods due to their abundant probiotics, and they also hold significance in terms of industrial and economic value (Behera and Balaji, 2021). Local tribes in Northeastern India create a wide range of fermented bamboo shoot-based products (Figs. 2 and 3). The eight states comprising Northeast India are Arunachal Pradesh, Assam, Meghalaya, Mizoram, Nagaland, Manipur, Sikkim, and Tripura. Among the residents in this region, 75 % belong to tribal communities. The presence of microorganisms such as *Lactobacillus species, Bacillus species, Candida species*, and *Saccharomyces cerevisiae* in fermented foods contributes significantly to their probiotic value (Das and Deka, 2012).

Well-known fermented bamboo shoot-based products include *mesu*, *soibum*, *soidon*, *soijim*, *ekung*, *heccha*, *eup*, *lung-siej*, and *hirring* (Table 1).

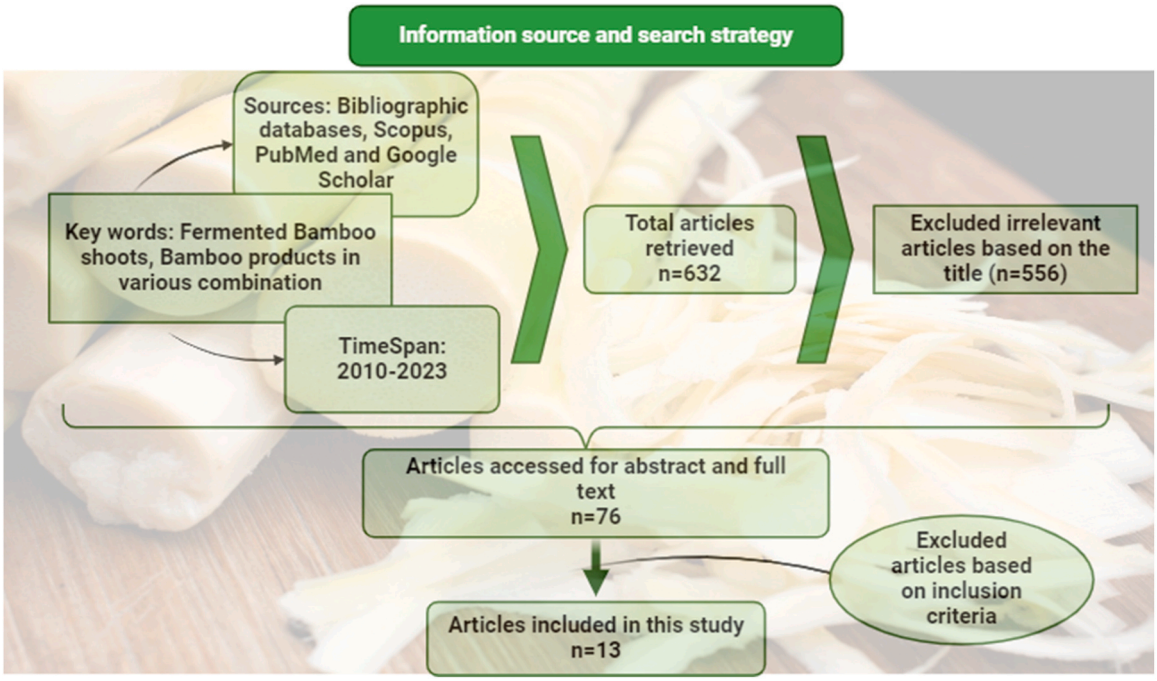

Fig. 1. The flowchart of the methodology used to extract the desired information.

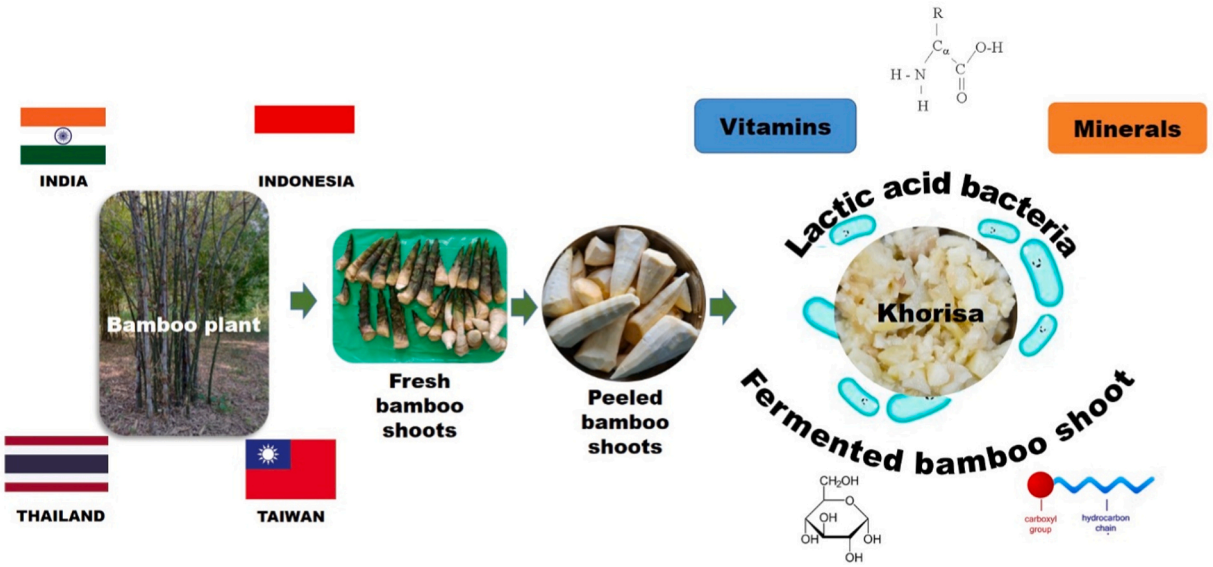

Fig. 2. Schematic representation of making of fermented bamboo shoot products along with the microbial load and nutritional parameters.

Fig. 3. Fermented bamboo shoot-based products from the North-eastern states of India.

3.1. Soibum

Soibum is a traditional fermented bamboo shoot-based product prepared by the inhabitants of Manipur from the tender bamboo shoots of species such as *Bambusa balcooa* Roxb., *Dendrocalamus hamiltonii* Nees & Arn. ex Munro, *Melacanna* sp. and *Bambusa tulda* Roxb. through a natural fermentation process. It is whitish and sour to taste and mainly consists of *Lactobacillus* sp. such as *L. curvatus* and *L. lactis*.

There are two ways to produce *Soibum*, the more popular one is called the kwatha or noney method in which polythene sheets or *Colocasia* leaves are packed along with bamboo shoot pieces in a specially designed chamber. The other way is called Andro, where the outer layers of the shoots are peeled off and thoroughly washed, after which the inner potion is cut into pieces. These pieces then undergo fermentation in earthen pots for a period of 3–12 months (Tamang et al., 2012). In Bishnupur, they add chopped shoots and water to a plastic tub and then leave it in an aerobic state for 15–20 days after which it is stored in pliable bags for 2–3 months (Nongdam and Tikendra, 2014).

3.2. Mesu

Mesu is a traditional fermented bamboo shoot-based product made by the Gorkha tribe of Sikkim. It is prepared from appetizing bamboo shoots from species such as *Bambusa tulda*, *Dendrocalamus hamiltonii* and *Dendrocalamus sikkimensis* Gamble ex Oliv. *Mesu* is prepared by removing leaves from shoots, slicing into fine pieces, and compressing tightly within the hollow bamboo stem. The tip of the container is shielded with plant leaves and allowed to undergo natural fermentation

Table 1
Details on the various fermented bamboo products with reference to microorganisms and nutrition.

Sl no	Fermented bamboo shoot products	Nature of the product	State/ Country	Bamboo species	Other ingredients	Fermentation time	Microorganism	Nutrition
	Bastenga	Sun dried	Nagaland (India)	Dendrocalamus hamiltonii, Bambusa tulda (Senapati et al., 2016)	Bamboo basket, Banana leaves (Senapati et al., 2016)	2–3 weeks (Senapati et al., 2016)	Lactic acid bacteria (Tamang et al., 2012)	NR
	Eeku	Moist & creamy solid mass	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, D. giganteus, D. longispathus, Bambusa balcooa, B. pallida, Melocanna baccifera (Roy et al., 2017)	Bamboo basket (eegin), Banana leaves (ekkam), Mature hollow bamboo stem (Roy et al., 2017)	1 month (Roy et al., 2017)	Lactic acid bacteria (Roy et al., 2017)	NR
	Eep	Sun dried product of eeku	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, D. giganteus, D. longispathus, Bambusa balcooa, B. pallida, Melocanna baccifera (Roy et al., 2017)	Bamboo basket (eegin), Banana leaves (ekkam), Mature hollow bamboo stem (Roy et al., 2017)	7–10 days (Roy et al., 2017)	Lactic acid bacteria (Roy et al., 2017)	NR
	Eepe	Sun dried produc of Kupe	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, D. giganteus, D. longispathus, Bambusa balcooa, B. pallida, Melocanna baccifera (Roy et al., 2017)	Bamboo basket (eegin), Banana leaves (ekkam), Mature hollow bamboo stem (Roy et al., 2017)	7–10 days (Roy et al., 2017)	Lactic acid bacteria (Roy et al., 2017)	Protein, Amino acid, Fatty acid, Vitamin, Minerals, carbohydrates, B-vitamin (Thiamine, Riboflavin,Niacin, Pyridoxine & Pantothenic acid), K, Mn, Cu, Ca, Fe, & P (Roy et al., 2017)
	Ekung	Moist solid mass	Arunachal Pradesh (India)	Bambusa balcooa Roxb. Dendrocalamus hamiltonii, Dendrocalamus giganteus, Bambusa tulda, Phyllostachys mannii (Behera and Balaji, 2021; Nongdam and Tikendra, 2014)	Airtight container, Bamboo basket (papur) kept in pit, one side open hollow bamboo stem (edung), Leaves to cover, Heavy bricks to produce liquid (Roy et al., 2017; Nongdam and Tikendra, 2014)	1–3 months (Behera and Balaji, 2021)	Lactobacillus plantarum, L. casei, L. Brevis, tetragenococcus halophilus (Behera and Balaji, 2021)	Moisture=94.7 %, Acidity=0.94 %, pH = 3.9, Ash= 14.0 % DM, Food value= 363.0 kcal/100 gDM, Protein= 30.1 % DM, Carbohydrate= 52.1 % DM, Fat=3.8 % DM, Ca=35.4 mg/100 g, K=168 mg/100 g, Na=10.9 mg/100 g (Behera and Balaji, 2021)
	Ekung	Solid sour and acidic	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, Bambusa balcooa. Dendrocalamus giganteus, Phyllostachys mannii, Bambusa tulda; (Tamang et al., 2012)	NR	1–3 months (Tamang and Tamang, 2009)	Lactobacillus plantaeum, L. brevis, L. casei, Tetragenococcus halophilus	Moisture: 94.7 %, pH: 3.9, acidity: 0.94 %, ash: 14.0 % DM, protein: 30.1 % DM, fat: 3.8 % DM, carbohydrate: 52.1 % DM, food value: 363.0 kcal/100 gm DM, Ca: 35.4 mg/100 gm, Na: 10.9 mg/100 gm, K: 168.6 mg/100 gm; (Tamang et al., 2012)
	Eup	Sun dried solid mass	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, Bambusa tulda (Roy et al., 2017)	Bamboo basket (papur) kept in pit, one side open hollow bamboo stem (edung) (Roy et al., 2017)	1–3 months (Behera and Balaji, 2021)	Lactobacillus plantarum, L. fermentum (Behera and Balaji, 2021)	Moisture=36.8 %, Acidity=0.8 %, pH=4.1 Ash=18.2 %DM, Fat=3.1 %DM, Protein=33.6 %DM, Carbohydrate= 45.1 %DM, Food value=342.7 kcal/ 100gDM, Na=3.4 mg/100 g, Ca=76.9 mg/ 100 g K=181.5 mg/100 g (Behera and Balaji, 2021)
	Eup	Sun dried solid mass	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, Bambusa tulda (Roy et al., 2017)	NR	1–3 months (Tamang and Tamang, 2009)	Lactobacillus plantarum, L. fermentum	Moisture: 36.8 %, pH: 4.1, acidity: 0.80 %, ash: 18.2 % DM, protein: 33.6 % DM, fat: 3.1 % DM, carbohydrate: 45.1 % DM, food value: 342.7 kcal/100 gm DM, Ca: 76.9 mg/100 gm, Na:

(*continued on next page*)

Table 1 (*continued*)

Sl no	Fermented bamboo shoot products	Nature of the product	State/ Country	Bamboo species	Other ingredients	Fermentation time	Microorganism	Nutrition
								3.4 mg/100 gm, K: 181.5 mg/ 100 gm; (Tamang, 2006)
	Hirring	Moist solid mass	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, Bambusa tulda (Roy et al., 2017)	Bamboo basket kept in pit leaves to cover (Behera and Balaji, 2021)	1–3 months (Behera and Balaji, 2021)	Lactobacillus plantarum, Lactobacillus lactis (Behera and Balaji, 2021)	Moisture=88.8 %, pH=4.0, Acidity=0.81 %, Protein=33.0 %DM, Carbohydrate= 49.3 %DM, Fat=2.7 %DM, Food value=353.5 kcal/100gDM, Ca=19.3 mg/100 g, K=272.4 mg/100 g, Na=3.4 mg/100 g (Behera and Balaji, 2021)
	Hirring	Moist solid mass	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, Bambusa tulda (Roy et al., 2017)	NR	1–3 months (Tamang and Tamang, 2009)	Lactobacillus plantarum, L. lactis	Moisture: 88.8 %, pH: 4.0, acidity: 0.81 %, ash: 15.0 % DM, protein: 33.0 % DM, fat: 2.7 % DM, carbohydrate: 49.3 % DM, food value: 353.5 kcal/100 gm DM, Ca: 19.3 mg/100 gm, Na: 3.4 mg/100 gm and K: 272.4 mg/100 gm (Tamang, 2006)
	Iku	Solid mass	Assam (India), Arunachal Pradesh (India)	Bambusa balcooa	Mature hollow bamboo stem, Earthen pot, Bamboo tray, Kubuli (Grinder), Banana leaves	30 days	Lactic acid bacteria	Protein, Vitamin, Carbohydrate, Fats, Minerals
	Jiang-sun	NR	Taiwan	NR	NR	3 Weeks – 1 month (Chen et al., 2010)	Lactobacillus plantarum, Enterococcus faecium	NR
	Khorisa	Sun dried solid	Assam (India)	Dendrocalamus giganteus (Sharma and Barooah, 2017)	Banana leaves (to cover), hollow bamboo stem (Chunga) for storage (Sharma and Barooah, 2017)	7–15 days (Sharma and Barooah, 2017)	Lactobacillus plantarum, L. pentosus, L. paracasei, L. brevis, L. collinoides (Sharma and Barooah, 2017)	pH=3.05, TSS=7.73 Brix, Titrable acidity =2.283, Sugar = 1.74 mg/100 g, Iron=2.30 mg/100 g, Calcium=1490.50 mg/100 g, Ascorbic acid=2.55 mg/100 g, Phosphorus=10.41 mg/100 g, Total alkaloids=0.23 % Protein= 1.42 mg/100 g Crude fibre=8.97 % (Sharma and Barooah, 2017)
	Kupe	Moist & creamy solid mass	Arunachal Pradesh (India)	Dendrocalamus hamiltonii, D. hookerii, D. giganteus, D. longispathus, Bambusa balcooa, B. pallida, Melocanna baccifera (Roy et al., 2017)	Bamboo basket (eegin), Banana leaves(ekkam), Mature hollow bamboo stem (Roy et al., 2017)	15–30 days (Roy et al., 2017)	Lactic acid bacteria (Roy et al., 2017)	Protein, Amino acid, Fatty acid, Vitamin, Minerals, carbohydrates, B-vitamin (Thiamine, Riboflavin,Niacin, Pyridoxine & Pantothenic acid), K, Mn, Cu, Ca, Fe, & P (Roy et al., 2017)
	Lung-siej	Moist solid mass	Meghalaya (India)	Dendrocalamus hamiltonii (Behera and Balaji, 2021)	Bamboo cylinder or glass bottle, Banana Leaves (Behera and Balaji, 2021)	1–12 months (Behera and Balaji, 2021)	Leuconostoc fallax, L. mesenteroides, Lactobacillus brevis, L. curvatus, and Lactococcus lactis (Behera and Balaji, 2021)	Protein=8.5 g/100 g, Fe=1 mg/100 g (Agrahar-Murugkar and Subbulakshmi, 2006)
	Mesu	Moist mass	Skkim (India)	Dendrocalamus hamiltonii, Bambusa tulda, Dendrocalamus sikkimensis, (Tamang et al., 2012)	NR	7–15 days (Tamang et al., 2012)	Lactobacillus plantarum, L. brevis, L. curvatus, Leuconostoc citreum, Pediococcus pentosaceous (Roy et al., 2017)	Moiture=89.9 %, Acidity=0.88 %, pH=3.9, Ash=15.0 %DM, Fat=2.6 %DM, Carbohydrate=55.6 %DM, Ca =7.9 mg/100 g, K =282.6 mg/100 g, Na =2.8 mg/100 g, Food value=352.4 kcal/100gDM (Tamang et al., 2012)
	Miyamikhri	Wet solid mass	Assam (India)	Bambusa balcooa, B. tulda, D. hamiltonii (Senapati et al., 2016)	Banana leaves to wrapped bamboo shoot, earthen pot to ferment (	4–5 days (Senapati et al., 2016)	Lactic acid bacteria (Tamang et al., 2012)	NR

(*continued on next page*)

Table 1 (*continued*)

Sl no	Fermented bamboo shoot products	Nature of the product	State/ Country	Bamboo species	Other ingredients	Fermentation time	Microorganism	Nutrition
					Senapati et al., 2016)			
	Naw Mai Dong	Moist solid	Thailand	NR	Pickled in bottles or jars (Kanpiengjai et al., 2022)	3 days (Kanpiengjai et al., 2022)	Lactic acid bacteria (Kanpiengjai et al., 2022)	pH value= 4–5.5 (Kanpiengjai et al., 2022)
	Poka Khorisa	Moistened solid mass	Assam (India)	Bambusa balcooa, Dendrocalamus hamiltonii (Senapati et al., 2016)	Garcinia pedunculata, Red chillies (Senapati et al., 2016)	4–12 days (Senapati et al., 2016)	Lactobacillus sp. (Senapati et al., 2016)	NR
	Soibum	Moist mass	Manipur (India)	Dendrocalamus hamiltonii (Wanap, Unap, Pecha), D. sikkimensis and D. giganteus (Maribop), Melaccona bambusoides (Moubi/Muli), Bambusa tulda (Utang), B. balcooa (Ching saniebi); (Tamang et al., 2012)	NR	3–12 months (Tamang et al., 2012)	Lactobacillus plantatum, L.brevis, L. coryniformis, L. delbrueckii Leuconostic fallax, L. mesenteroides Lactococcus lactis, Streptococcus lactis, Enterococcus durans, Bacillus subtilis, and yeasts like Candida, and Saccharomyces (Behera and Balaji, 2021)	Moisture: 92.0 %, pH: 3.9, acidity: 0.98 %, ash: 13.3 % DM, fat: 3.2 % DM, protein: 36.3 % DM, carbohydrate: 47.2 % DM, food value: 362.8 kcal/100 gm DM, Ca: 16.0 mg/100 gm, Na: 2.9 mg/100 gm, K: 212.1 mg/ 100 gm33. (Tamang et al., 2012)
	Soibum	Moist mass	Manipur (India)	Bambusa tulda (Utang), B. balcooa (Ching saniebi, Dendrocalamus hamiltonii, Melocanna baccifera (Moubi/Muli) (Behera and Balaji, 2021)	Traditional bamboo chamber (Noney), Bulky roasted earthen pot (Andro type); (Roy et al., 2017)	3–12 Months (Behera and Balaji, 2021)	Lactobacillus plantatum, L. Brevis, L. coryniformis, L. delbrueckii Leuconostic fallax, L. mesenteroides plantatum, L. brevis, Streptococcus lactis, Enterococcus durans, Bacillus subtilis and Yeast like Candida, Saccharomyces (Behera and Balaji, 2021)	Moisture=92 %, Acidity=0.98 %, pH=3.9, Fat=3.2 %DM, Carbohydrate =47.2 %DM, Food value= 362.8 kcal/100gDM, Protein=36.3 %DM, Ca=16.0 mg/100 g, K=212.1 mg/100 g, Na=2.9 mg/100 g (Behera and Balaji, 2021)
	Soidon	Moist solid mass	Manipur (India)	Bambusa tulda Roxb., Dendrocalamus giganteus and Melocanna baccifera Trin.; (Tamang et al., 2012)	NR	3–7 days (Tamang et al., 2012)	Lactobacillus brevis, L. curvatus, L. Plantarum, Leuconostoc fallax, Lactococcus lactis (Behera and Balaji, 2021)	Moisture: 92.2 %, pH: 4.2, acidity: 0.96 %, ash: 13.1 % DM, fat: 3.1 % DM, protein: 37.2 % DM, carbohydrate: 46.6 % DM, food value: 363.1 kcal/100 gm DM, Ca: 18.5 mg/100 gm, Na: 3.7 mg/100 gm, K: 245.5 mg/ 100 gm; (Tamang et al., 2012)
	Soidon	Moist solid mass	Manipur (India)	Bambusa tulda, Dendrocalamus giganteus and Melocanna bambusoides, Teinostachyum wightii (Behera and Balaji, 2021)	Earthen pots or plastic container (to storage), leaves of Garcinia pedunculata Roxb. (for increasing of flavour) (Roy et al., 2017; Behera and Balaji, 2021)	3–7 days (Behera and Balaji, 2021)	Lactococcus lactis, Lactobacillus brevis, Leuconostoc fallax. (Behera and Balaji, 2021)	Moisture=92 % pH=4.2, Acidity=0.96 %, Carbohydrate=46.6 %, Fat=3.1 %DM, Protein=37.2 %DM, Food value =363.1 kcal/100gDM, Ca=18.5 mg/100 g, K=245.5 mg/100 g, Na= 3.7 mg/100 g (Behera and Balaji, 2021)
	Soijim	Liquid, acidic, sour taste	Manipur (India)	Bambusa tulda, Dendrocalamus giganteus, Melocanna baccifera (Tamang and Tamang, 2009)	NR	3–7 days Tamang et al., 2012)	Lactobacillus brevis, Leuconostoc fallax, L. mesenteroides, L. lactis (Behera and Balaji, 2021)	Moisture: 92.2 %, pH: 4.2, acidity: 0.96 %, ash: 13.1 % DM, fat: 3.1 % DM, protein: 37.2 % DM, carbohydrate: 46.6 % DM, food value: 363.1 kcal/100 gm DM, Ca: 18.5 mg/100 gm, Na: 3.7 mg/100 gm, K: 245.5 mg/ 100 gm; (Tamang et al., 2012)
	Suansun	NR	China	NR	NR	NR	Lactiplantibacillus plantarum, Lactiplantibacillus fermentum, Lactiplantibacillus brucei, Lactic acid bacteria (Hu et al., 2021)	NR
	Tabah Bamboo Shoot	Moist mass	Bali (Indonesia)	Gigantochloa nigrociliata (	NR	13 days; (Darmayanti et al., 2014)	Lactic acid bacteria	pH= 3.09, water=92.2 %, protein (2.29 %), fat=0.23 %),

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Table 1 (*continued*)

Sl no	Fermented bamboo shoot products	Nature of the product	State/ Country	Bamboo species	Other ingredients	Fermentation time	Microorganism	Nutrition
				Darmayanti et al., 2014)				carbohydrates=1.68 %, and fibers=3.07 %; HCN=7.97 mg/100 g.
	Tabah Bamboo Shoot	NR	Bali (Indonesia)	Bambusa balcooa, Dendrocalamus giganteus, D. hamiltonii, D. strictus, Melocanna baccifera, D. longispathus, B. tulda, Phyllostachys bambusoides, D. asper, Gigantochloa atter, G. robusta, G. nigrociliata (Kanpiengjai et al., 2022)	Pickled in glass bottle jar (Kanpiengjai et al., 2022)	13 days (Kanpiengjai et al., 2022)	Lactic acid bacteria (Kanpiengjai et al., 2022)	Water=92.2 %, pH=5.01–3.09, Protein=2.29 %, Fat=0.235, Carbohydrates= 1.68 %, Hydro cyanic acid=7.97 mg/ 100 g (Kanpiengjai et al., 2022)
	Tuaithur	Moist solid mass	Assam (India)	Dendrocalamus hamiltonii, D. hookerii, Bambusa tulda (Roy et al., 2017)	Cylindrical vessel made by bamboo stem, leaves for covering (Tamang et al., 2012)	6–7 days (Tamang et al., 2012)	Lactobacillus plantarum, L. Brevis, P. pentosaceou, Lactococcus lactis, Bacillus circulans, B. firmus, B. sphaericus, B. subtilis (Tamang et al., 2012)	Moisture=92.3 %, pH=4.0, Acidity=0.83 %, ash=4.6 %DM, Fat=3.4 % DM, Protein=4.6 %DM, Carbohydrate= 87.4 %DM, Food value= 398.6 kcal/100 g DM (Tamang et al., 2012)

*DM= dry mass

in anaerobic conditions for 15 days. *Mesu* is rich in *Lactobacillus brevis*, *L. plantarum*, *L. curvatus*, *Leuconostoc citreum* and *Pediococcus pentosaceus*. It is consumed as a pickle and possesses a distinct flavour and taste. The action of microorganisms that occur during the fermentation of bamboo shoots imparts colour and texture to the bamboo fermented product *mesu* (Behera et al., 2018; Tamang & Tamang, 2009*)*.

3.3. Soidon

Soidon is a fermented product made of bamboo shoots sold by Meitei women in the state of Manipur. The matured shoots of *Bambusa tulda*, *Melocanna bambusoides* Trin., *Dendrocalamus giganteus* and *Teinostachyum wightii* (Munro) are used to produce *soidon*. Initially the tips of the matured shoots, which are the main ingredient for the *soidon* preparation, are removed, then the outer casings and the lower parts are removed. These tips are then immersed in an earthen vessel which consists of water and sour liquid from the previous batch and incubated for 3–7 days at room temperature for the fermentation process. Bishnupur village which is situated in Manipur is known to produce the best *soidon*, which is eaten as a pickle or curry. The microorganisms found in *soidon* are *L. lactis*, *L. brevis* and *Leuconostoc fallax* (Jeyaram et al., 2019; Soibam & Ayam, 2018; Tamang et al., 2012).

3.4. Ekung

Ekung is a product crafted by Nishi, the predominant ethnic group in the state of Arunachal Pradesh. It is pronounced as 'iku' or 'hikku' and is available in local markets. The mature shoots of *B. balcooa*, *D. giganteus*, *Phyllostachys mannii* Gamble (syn. *Phyllostachys assamica* Gamble), *D. hamiltonii* and *B. tulda*, are used in the preparation of *Ekung*. The shoots are collected, defoliated and cut into small pieces. A pit is dug near a water body and within the pit, pieces of bamboo are put in a bamboo basket, covered with leaves, and then sealed. It is left for fermentation for 1–3 months. Vegetables, fish and meat can be used to prepare *Ekung*. The microorganisms that are mainly present in *Ekung* are *T. halophilus*, *L. plantarum*, *L. brevis*, and *L. casei* (Tamang et al., 2012; Behera et al., 2018).

3.5. Eup

The term "*Eup*" is derived from the lexicon of the Nishi language. It is a dehydrated form of fermented bamboo shoot produced in Arunachal Pradesh. It is used as a curry paired with fish, meat or vegetables. Mature bamboo shoots of species such as *Bambusa balcooa* and *Dendrocalamus hamiltonii* are cut into pieces and sundried for 5–10 days until the white colour transforms into chocolate brown and the resulting product can be preserved for about two years. *L. plantarum* and *L. fermentum* are the major microorganisms found in *Eup* (Behera and Balaji, 2021; Tamang et al., 2012).

3.6. Lung-siej

Lung-siej, a fermented bamboo shoot-based product that is a delicacy in the state of Meghalaya is made from *Dendrocalamus hamiltonii*. It is prepared in a bamboo cylinder; bamboo shoots are made into small pieces after removing leaves. These pieces are placed inside the bamboo cylinders, sealed with leaves, and secured by tying the rim with a thread commonly made of grass. The bamboo cylinders are submerged upside down near a water body for approximately two months to undergo fermentation. *Lung-siej* is commonly consumed in combination with fish and meat and is rich in lactic acid bacteria (Mir et al., 2018; Tamang et al., 2012).

3.7. Hirring

Hirring is a fermented bamboo shoot-based product made by the Apatani tribe from Arunachal Pradesh. It is popularly called 'hitak' or 'hitch' by the Nishi ethnic group. To produce *hirring*, bamboo shoots are longitudinally cut into 2–3 pieces, crushed and then placed in a bamboo basket with bamboo leaves. The baskets are subsequently positioned in a quarry (pit), covered with banana leaves, sealed, and left to ferment for a period of three months. It is suitable for consumption as a curry and is available for purchase in local markets. The predominant microorganisms present in *Hirring* include *L. plantarum* and *L. lactis* (Behera and Balaji, 2021; Tamang et al., 2012).

3.8. Bastenga

Bastenga is a fermented bamboo shoot-based product made by the Naga tribe from Nagaland. '*Bas*' means 'smelly' and '*tenga*' means 'sour'. It is of two types: wet and dried. The wet *bastenga* is off-white in colour whereas dried bastenga is golden brown in colour and both types give off a pungent smell. *Bastenga* is made from *Dendrocalamus hamiltonii* and *Bambusa tulda* and contains lactic acid bacteria (Tamang et al., 2012; Yeptho et al., 2021). The Lotha tribe of Woka also traditionally prepare *Bastenga* and is known as 'Rhujuk' in their dialect. In the first step the outer coverings are removed from young tender shoots. Subsequently, the specimens are fragmented into small pieces and firmly compressed into bamboo baskets enveloped with banana leaves. A perforation is introduced at the centre, and a receptacle is positioned at the base for juice collection. It is left in shade for fermentation for approximately 2–3 weeks and the product obtained is known as *Rhuchak* (wet *Bastenga*). The fermented shoots are separated and sun-dried using bamboo shoots to get *Rhuchon* (dry *Bastenga*) (Senapati et al., 2016).

3.9. Khorisa

Khorisa, a fermented bamboo shoot-based product, is a significant dietary component for both rural and urban populations in Assam. Prepared traditionally by the locals, *Khorisa* preparation involves harvesting mature bamboo shoots, typically from *Dendrocalamus giganteus*. The outer layers are removed, and the shoots are washed before being hammer-milled using a traditional wooden husking pedal called a '*Dheki*'. The resulting pulp is packed into earthen pots and fermented in anaerobic conditions for 12 days. The excess water is pressed out and the fermentation materials are sun-dried for three days, resulting in a product with a distinctive sour aroma and a mild acidic taste. Jars are utilized for storing *Khorisa*, which is incorporated into traditional meals featuring fish, meat and sweets (Thakur et al., 2016; Senapati et al., 2016). *Khorisa* contains microorganisms such as *Lactobacillus plantarum*, *L. pentosus*, *L. paracasei*, *L. brevis*, and *L. collinoides* (Sharma and Barooah, 2017).

3.10. Poka khorisa

Poka khorisa, an ethnic fermented bamboo shoot-based product from Assam, is prepared using young edible shoots of *Bambusa balcooa* and *Dendrocalamus hamiltonii*. These shoots, defoliated and hammer-milled, are combined with *Garcinia pedunculata* Roxb. Ex Buch.-Ham. fruit and dried chillies, packed into pots, and tightly pressed. The pots are sealed with banana leaves and undergo anaerobic fermentation for 12 days. After removing excess water from the pulp, the product is stored in jars. *Poka khorisa* is whitish in colour with a subtle aroma and a sour taste. It is used in various dishes, pickle making, and also as a medicine. *Lactobacillus* species are the microorganisms found in *poka khorisa* (Senapati et al., 2016).

Various fermented bamboo shoot-based products including *Soijim*, *Tabah*, and *Tuaithur*, are prevalent. *Soijim*, characterized by its acidic and sour taste, is crafted by Manipur residents using bamboo species such as *Bambusa tulda*, *Dendrocalamus giganteus* and *Melocanna baccifera* (Roxb.) Kurz (syn. *Melocanna bambusoides* Trin.). The microorganisms involved in *Soijium* production includes *Lactobacillus brevis*, *Leuconostoc fallax*, *L. mesenteroides*, and *L. lactis* (Tamang and Tamang, 2009). *Tabah*, originating from Bali, is stored in pickled glass jars, and prepared from bamboo varieties such as *Bambusa balcooa*, *Dendrocalamus giganteus*, *D. hamiltonii*, *D. strictus* (Roxb.) Nees, *Melocanna baccifera*, *D. longispathus* (Kurz) Kurz, *B. tulda*, *Phyllostachys bambusoides*, *D. asper* (Schult. & Schult.f.) Backer, *Gigantochloa atter* (Hassk.) Kurz ex Munro, *G. robusta* Kurz and *G. nigrociliata* (Buse) Kurz. Lactic acid bacteria contribute to the fermentation of *Tabah* (Kanpiengjai et al., 2022). *Tuaithur*, a moist solid mass fermented product from Assam, is crafted using *Dendrocalamus hamiltonii*, *D. hookerii* Munro and *Bambusa tulda* species. The fermentation vessel is typically a cylindrical structure made from bamboo stems, covered with leaves. Microorganisms present in *Tuaithur* include *Lactobacillus plantarum*, *L. brevis*, *P. pentosaceou*, *Lactococcus lactis*, *Bacillus circulans*, *B. firmus*, *B. sphaericus* and *B. subtilis* (Tamang et al., 2012).

4. Nutraceutical profile

Bamboo shoots are recognized for their nutritional significance, attributed to the presence of bioactive compounds that confer health benefits and protect against chronic and degenerative ailments. They serve as a rich reservoir of vitamins, proteins, amino acids, beta-carotene, minerals, and carbohydrates, as well as various phenolic compounds. Thiamine, niacin, vitamin A, vitamin B6, and vitamin E are notably abundant in fresh bamboo shoots.

Moreover, bamboo shoot-based diets are characterized by elevated levels of dietary fibres such as hemicellulose, cellulose, pectin and lignin, along with phytosterols. These components play pivotal roles in preventing colon cancer and maintaining optimal blood cholesterol levels. Phytosterols exhibit cholesterol-lowering, anticarcinogenic, neuroprotective, and antioxidant properties.

The bioactive substances present in bamboo shoots encompass phenolic acids (e.g., catechin, caffeic acid, protocatechuic acid), p-coumaric acid, p-hydroxybenzoic acid, ferulic acid, syringic acid, chlorogenic acid, gallic acid, vanillic acid and various flavonoids. Many of these compounds exhibit therapeutic potential, including antioxidant, anti-inflammatory and anti-cancer activities, as reported by Acharya et al. (2023) and Nongdam and Tikendra (2014).

Bamboo shoots are distinguished by their high potassium content (620–1100 mg/100 g), surpassing that of potato and spinach. Additionally, they are a notable source of magnesium (10.09 mg/100 g), essential for body metabolism. Selenium, a remarkable element found in certain bamboo species, is also present. The shoots provide 17 amino acids, including eight essential for the human body, along with a substantial amount of tyrosine, constituting 57–67 % of the total amino acid content.

Bamboo shoots from *Bambusa* species contain secondary metabolites such as glucosides, choline, cyanogens, and betaine, renowned for their efficacy in treating coughs and diarrhoea. The taste profile of bamboo is influenced by factors such as total sugar, total amino acids (including aspartic acid, glutamic acid, glycine) and tannins, as elucidated by Kumar et al. (2017).

5. Conclusion

In conclusion, fermented bamboo shoots stand out as a remarkable culinary tradition deeply entrenched in the cultural fabric of Northeastern India. This review sheds light on the diverse array of fermented bamboo shoot-based products, reflecting the rich culinary diversity stemming from traditional practices. These products, including *soibum, mesu, soidon, ekung, eup, lung-siej, hirring, bastenga, khorisa, poka khorisa*, and others, are not only valued for their unique flavours and textures but also for their significant therapeutic and nutritional attributes. The therapeutic properties of fermented bamboo shoots, ranging from anti-aging and anticancer benefits to antioxidant and cardioprotective effects, underscore their potential as functional foods enriched with probiotics. The presence of diverse microorganisms, including Lactobacillus, Bacillus, Candida, and Saccharomyces species, contributes to the fermentation process, enhancing the nutritional profile and health-promoting properties of these products. Further research and exploration into the therapeutic potential and culinary diversity of fermented bamboo shoot-based products are warranted to fully appreciate their multifaceted significance.

CRediT authorship contribution statement

Jangila Basumatary: Validation, Methodology, Data curation. **Swarna Kamal Dey:** Writing – original draft, Formal analysis. **Sushil Kumar Middha:** Writing – review & editing, Validation, Supervision, Data curation. **Pranjoy Brahma:** Methodology, Data curation. **Sunita Mushahary:** Methodology, Data curation. **P Hemalatha:** Writing – original draft, Validation, Data curation. **K N Hemavathi:** Writing – original draft, Validation, Data curation. **Mrinal Kalita:** Methodology, Formal analysis, Data curation. **Talambedu Usha:** Writing – original draft, Methodology, Data curation. **Arvind Kumar Goyal:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Conceptualization. **Ankit Shah:** Validation, Formal analysis, Data curation.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Data availability

No data was used for the research described in the article.

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