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Traditional fermented foods of northeast India: Diversity, preparation techniques, and microbial associations-a review

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Abstract

Northeast India, comprising the Seven Sister states, is a region of rich ethnic, cultural, and ecological diversity, where traditional fermented foods play a central role in diet and culture. Indigenous communities utilize local substrates such as bamboo shoots, rice, vegetables, soybeans, and fish to produce a wide variety of fermented products, including Soibum, Lung-siej, Tuaithar, Hor, Apong, Zutho, Sinki, Kinema, Axone, Ngari, and Hentak. Fermentation processes rely on lactic acid bacteria, *Bacillus* spp., yeasts, and natural starter cultures, enhancing nutritional value, digestibility, flavor, and shelf life while providing probiotic and antimicrobial benefits. These foods reflect deep traditional knowledge, integrating microbial diversity, environmental adaptation, and cultural practices. Their preparation supports food security, sustainable livelihoods, and the preservation of indigenous heritage, highlighting the significance of fermentation as a cost-effective, health-promoting, and culturally embedded food technology in the region.

Keywords: cultural heritage, Lactic Acid Bacteria, northeast India, probiotics and traditional fermented foods

Introduction

Northeast India is linked to the rest of India through a narrow passage known as the Siliguri Corridor, flanked by Nepal and Bangladesh. This region encompasses the Seven Sister states: Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, and Tripura. Collectively, these states cover approximately 8% of India's total geographical area and are home to around 40 million people, accounting for about 3.1% of the nation's population (Mao & Hynniewta, 2000; Chatterjee *et al.*, 2006)^[8]. Agriculture serves as the primary occupation for the indigenous tribes of the region. A traditional farming method known as 'jhum' or shifting cultivation is widely practiced, wherein land is cleared, cultivated for a few years, and then left fallow to regenerate. This technique supports the growth of various crops, including cereals, vegetables, and fruits (Mao & Hynniewta, 2000)^[20]. The area is home to several botanical rarities and curiosities and is frequently referred to as the Cradle of Flowering Plants. Leading conservation organizations worldwide have made the northeastern region a priority due to its high level of biodiversity. Seventy-five percent of the inhabitants in this area are tribal people (Agrahar-Murungkar & Subbulakshmi 2006)^[1].

One of the most significant factors in distinguishing one ethnic group from another is food. The fact that urban-dwelling ethnic groups continue to have a strong need for wild edibles due to their traditional eating patterns and way of life is also remarkable (Asati & Yadav 2003; Medhi *et al.* 2013)^[3]. The different ethnic groupings in North-East India have different methods for making traditional fermented

meals. Due to variations in the substrate and fermentation process, these foods include a wide range of microflora and have a high nutritional value (J. P. Tamang *et al.* 2012). Since ancient times, people have practiced and passed down the knowledge of making these fermented foods utilizing basic processing methods (Nehal 2013)^[26]. Lactic Acid Bacteria (LAB), which are employed as probiotics, have been discovered to be abundant in traditional fermented meals (Satish Kumar *et al.*, 2013)^[32]. According to Prabhurajeshwar and Chandrakanth (2017)^[28]. Lactic acid bacteria are known to produce antimicrobial substances such as hydrogen peroxide, organic acids, and bacteriocin that prevent the growth of harmful bacteria. Additionally, they can reduce serum cholesterol, which may help prevent coronary heart disease (Shehata *et al.* 2016)^[35]. Probiotics were regarded by the World Health Organization (WHO) as the second most essential immune defense in 1994 due to rising antibiotic resistance to routinely given drugs (Levy 2000)^[17]. The WHO/FAO classified probiotics as live bacteria that provide health benefits when given in sufficient doses in 2006. According to Al Kassaa *et al.* (2014)^[2], lactic acid bacteria (LAB) are probiotics that aid in reducing or blocking the symptoms of viral illnesses. Known by another name, immunobiotics, they help the immune system in eliminating viruses (Chiba *et al.* 2013)^[9]. Additionally, probiotics possess immunomodulatory properties that make them useful in treating gastrointestinal disorders, including inflammatory bowel disease (IBD) (Miele *et al.*, 2009)^[23]. Fermentation is the oldest and most cost-effective way to extend food's shelf life and maintain its nutritional content. The flavor and texture of fermented foods are enhanced, as

they contain vital amino acids. These bioactive compounds support health, vitamins, and minerals, as well as antioxidant and antimicrobial properties that enhance human digestion (Farhad *et al.*, 2010)^[11].

India has always included fermented foods in its meals since fermentation is a low-cost technology that preserves food, increases its nutritional content, and improves its sensory appeal (Marco *et al.*, 2017). Additionally, fermentation enhances the food's overall quality, flavor, and aroma while increasing digestibility, breaking down complex carbs into simpler ones, and improving the bioavailability of vital amino acids, vitamins, and minerals (Şanlı *et al.*, 2017). According to Sharma *et al.* (2013)^[34]. Fermented food products have positive health impacts by acting as nutraceutical agents.

This review provides a comprehensive synthesis of traditional fermented foods from Northeast India by integrating ethnographic documentation, microbial diversity, and their nutritional and functional significance. Unlike previous reports that describe individual fermented products, the present review compiles a wide range of indigenous fermented foods across the Seven Sister states and highlights their associated microorganisms, substrates, and traditional preparation practices. The review further emphasizes the role of Lactic Acid Bacteria (LAB), *Bacillus spp.*, and yeasts in enhancing nutritional quality, digestibility, and probiotic potential. Additionally, it links traditional fermentation knowledge with contemporary perspectives on food security, sustainable utilization of local resources, and the preservation of indigenous culinary heritage. By consolidating scattered information and identifying research gaps in microbial characterization and functional evaluation, this review provides a valuable framework for future research and the potential development of value-added fermented foods from Northeast India.

Materials and Methods

Literature search: The present review was prepared through a comprehensive survey of published scientific literature related to traditional fermented foods of Northeast India. Relevant articles were collected from major academic databases including Google Scholar, Scopus, Web of Science, and PubMed. Additional information was obtained from books, review papers, and reports published by research institutions and universities.

Search keywords : Literature searches were conducted using combinations of keywords such as “fermented foods of Northeast India,” “traditional fermented foods,” “indigenous fermented soybean,” “ethnic fermented foods,” “microbial diversity in fermented foods,” “lactic acid bacteria,” and the names of specific fermented products including Soibum, Axone, Kinema, Ngari, Hentak, Apong, Zutho etc.

Types of fermented foods

1. Fermented Bamboo shoot

(a) Soibum/Soidon: These products are indigenous to the state of Manipur and are made from fermented bamboo shoots. They are used to the societal customs of the Manipuri people and constitute a necessary component of their diet. *Soibum* is made solely from the succulent bamboo

shoots of the following species: *Melocana bambusoide*, *Bambusa tulda*, *B. balcona*, *Dendrocalamus giganteus*, *D. sikkimensis*, and *D. hamiltonii*. From June to September, when bamboo shoots begin to sprout, the fermentation process is conducted. The vast majority of Manipur's known *soibum* manufacturing locations are in the hills, and they depend on the quantity and availability of the raw material (Jeyaram *et al.*, 2009; Bhatt *et al.*, 2003). According to Tamang *et al.* (2008), the organisms responsible for *soibum* fermentation include *Lactobacillus plantarum*, *Lactobacillus brevis*, *Lactobacillus coryniformis*, *Lactobacillus lactis*, *Leuconostoc fallax*, *L. mesentroides*, *Enterococcus durans*, *Streptococcus lactis*, *Bacillus subtilis*, *B. licheniformis*, *B. coagulans*, and the yeasts *Candida sp.*, *Saccharomyces sp.*, and *Torulopsis sp.* *Soibum* is produced from mature shoots of *Teinostachyum wightii* (Munro), *Dendrocalamus giganteus*, *Melocanna bambusoides* Trin., and *Bambusa tulda*. The tips of the matured shoots the primary component of the *soidon* preparation are first removed, followed by the lower portions and outer casings. The fermentation process is then allowed to proceed for 3-7 days at room temperature after these tips are submerged in an earthen jar filled with water and sour liquid from the prior batch. The best *soidon*, which is consumed as a curry or pickle, is produced in the village of Bishnupur, which is located in Manipur. *Soidon* contains the microorganisms *Leuconostoc fallax*, *Lactobacillus lactis*, and *Lactobacillus brevis* (Tamang *et al.* 2012, Behera *et al.* 2018)^[4].

(b) Lung-siej: *Lung-siej* is a fermented bamboo shoot delicacy native to Meghalaya, traditionally made from *Dendrocalamus hamiltonii*. The process begins by removing the leaves from the bamboo shoots and cutting them into small pieces. These pieces are then packed into hollow bamboo cylinders, which are sealed with leaves and fastened using grass-derived threads. The sealed cylinders are placed upside down and submerged near a water body, where they are left to ferment naturally for around two months. This fermentation process enriches the product with lactic acid bacteria. *Lung-siej* is typically served alongside fish or meat dishes (Mir *et al.*, 2018; Tamang *et al.*, 2012)^[24, 46].

(c) Bas-Tenga: *Bas-tenga* is a traditional fermented bamboo shoot product prepared by the Lotha Naga tribe of Nagaland, utilizing young shoots of *Dendrocalamus hamiltonii* and *Bambusa tulda*. The process begins with the removal of the sheaths to expose the tender inner portion, which is then finely chopped and placed in a tightly compressed bamboo basket, covered with banana leaves. A central opening is created to facilitate the drainage of the extracted juice. This fermentation process is sustained for a period of 2-3 weeks until the bamboo shoots are completely devoid of their liquid content. Following fermentation, the shoots are dried, with different grades available depending on the cutting and slicing techniques used. The extracted juice from *Bas-tenga* possesses a long shelf life and can be preserved for consumption over several years (Jamir and Deb, 2014)^[13].

(d) Tuaitar: *Tuaitar* is a fermented bamboo shoot product predominantly consumed by the Hmar, Baite, and Hrangkhoh tribes in Assam and Mizoram. Its traditional preparation involves using tender young bamboo shoots from species such as *Melocanna bambusoides*,

Dendrocalamus hamiltonii, and *Bambusa tulda* (Nongdam, 2015) ^[27]. The process of preparing *Tuaitar* involves the collection of bamboo shoots, followed by the removal of their hard outer casings. The soft inner portions are then chopped and sliced into smaller pieces, thoroughly washed, and cleaned with water. Subsequently, these pieces are tightly packed into a bamboo cylinder or a glass jar. The water from the bamboo shoots is drained continuously over a period of 2 to 3 days. A small amount of fresh water is then added, and the mixture is stored in an airtight container to undergo anaerobic fermentation for 6 to 7 days. Upon completion of the fermentation process, *Tuaitar* is deemed ready for consumption. It can be preserved for several months in an airtight container at ambient temperature. *Tuaitar* is typically consumed as a curry alongside meat or fish, and it can also be paired with vegetables such as brinjal and Arum stems. Additionally, a pickle is produced from *Tuaitar*, which can be stored for extended periods. This product is commonly available in local markets in Mizoram. The pH of *Tuaitar* ranges from 4.0 to 6.0, and its caloric value is reported to be 398.6 Kcal per 100 grams (Chakrabarty *et al.*, 2014) ^[17].

(e) Up-thor: *Up-thor* is a traditional fermented bamboo shoot product prepared by the Karbi tribe of Assam and Meghalaya primarily using the tender shoots of *Dendrocalamus hamiltonii* (locally known as *Kaipho*). The outer sheaths are first removed to reveal the soft inner core, which is then chopped and separated into apical (tender) and basal (hardier) portions. While the tender part is consumed fresh (*Up-wai*), the harder base is used for fermentation. The chopped shoots are packed into a *Langpong*, a hollow bamboo internode sealed at both ends. A hole is made at one end to stuff the shoots, after which it is sealed with a wooden plug to make it airtight. The sealed *Langpong* is then either buried in soil or immersed in water for about 3 days to allow fermentation. Once fermented, the product known as *Up-thor* develops a distinct sour flavor and can be preserved for consumption throughout the year. In addition, dried forms of the shoots (*Akreng*) are prepared by sun-drying, wrapping in banana leaves, and storing near the fireplace for long-term use (Teron, 2024).

2. Fermented rice beverage

(a) Hor : *Hor*, or traditional alcoholic beverage, holds an important place in the socio-cultural life of the Karbis. *Hor Alank*, a type of rice beer, is prepared by fermenting cooked rice with a locally made starter culture known as *Thap*. When this rice beer is distilled, it produces *Hor Arak*. *Hor Alank* is mainly served during ceremonies such as *Adam Asar* (marriage rituals) and *Seh Karkli* (worship practices). On the other hand, *Hor Arak* is more widely used in social gatherings, including funeral rites, and is also offered to guests as a gesture of respect. Both varieties, however, are enjoyed as refreshing drinks by the community (Teron, 2006) ^[52]. The associated yeasts reported include *Saccharomyces cerevisiae*, *Pichia burtonii*, and *Wickerhamomyces anomalus* (Loying *et al.*, 2024) ^[18]. It is traditionally prepared by fermenting cooked rice with a yeast culture called *Thap*. Inferior quality rice is generally used, cooked, and spread on a special bamboo mat known as *Antar*, which is used only for this purpose. Once cooled and broken into fine grains, the rice is mixed with powdered

Thap and stored in earthen pots (*Tebuk*) or utensils (*Pho-le*) for three days in summer or four days in winter to ferment. During collection, a bamboo sieve (*Hengru*) is placed at the center, and the rice beer (*Horlank*) is drawn with a gourd shell (*Lankjak*). The leftover fermented rice before distillation is called *Bechurang*. Finally, water is added, mixed thoroughly, and kept overnight, a step known as *Hor Kangthur* (Teron, 2006) ^[52].

(b) Apong: *Apong* is a traditional alcoholic beverage of Arunachal Pradesh, also common among the Mishng community of Assam, and holds cultural significance for the people of this region. Its preparation requires a starter culture known as *ipoh*, which contains yeasts responsible for fermentation (Tiwari and Mahanta, 2007) ^[58]. The associated yeasts include *Saccharomyces cerevisiae* (dominant), *Hanseniaspora sp.*, *Kloeckera sp.*, *Pischia sp.*, and *Candida sp.* (Tanti *et al.*, 2010) ^[48]. To prepare *Ipoh*, rice is dried, ground into powder, and mixed with seed and bark powders of *Veronia cinerea* and *Clerodendron viscosum*. The mixture is made into a paste with water from previously prepared *apong*, shaped into small discs, and dried on bamboo mats for 3-4 days. These dried cakes can be stored for up to a year (Tiwari and Mahanta, 2007). For brewing *apong*, rice is boiled in a wide-bottom vessel without overcooking, then mixed with *ipoh* in a suitable quantity. The mixture is transferred to a vessel with a lid, a little water is added, and fermentation is carried out at room temperature for 3-5 days until a strong alcoholic aroma develops. Before consumption, the product is diluted with water (Tiwari and Mahanta, 2007) ^[58].

(b) Xaj-pani: The Ahoms of Assam traditionally prepare *xaj-pani*, a rice beer of cultural and ritual importance, consumed during religious ceremonies, Bihu festivals, and as a refreshing drink after labor (Saikia *et al.*, 2007) ^[29]. Its starter culture, *vekur pitha*, is made by drying powdered leaves of *Lygodium flexuosum*, *Leucas aspera*, *Cissampelos*, *Pereira*, *Scoparia dulcis*, *Cinnamomum glanduliferum*, and *Piper betle*, wrapped in banana leaves (*Musa paradisiaca*) for 4-5 days over a fireplace. The dried cakes provide *Saccharomyces cerevisiae* and can be stored for later use. To prepare *xaj-pani*, Bora rice (Sali variety) is cooked, cooled, and mixed with powdered *vekur pitha*, then transferred to an earthen pot (*kalah*) and left to ferment in a dark corner for 4-5 days. The concentrated alcoholic juice is collected by filtration using rice straw or a vessel to separate the liquid from solids. The resulting *xaj-pani* is sweet, aromatic, and highly alcoholic (Saikia *et al.*, 2007) ^[29].

(c) Zutho: *Zutho* is a traditional rice beer prepared from sprouted rice grains by the Angami tribe of Nagaland. The fermentation is dominated by *Saccharomyces cerevisiae* (Sekar and Mariappan, 2007) ^[33]. For its preparation, unhulled glutinous rice is soaked for three days, drained, and allowed to germinate for 3-4 days in summer and up to seven days in winter. The sprouted rice, along with its hulls, is then pounded into a grist, while polished glutinous rice is soaked, drained, and pounded separately. Boiling water is gradually added to the rice powder to form a soft porridge, which is cooled and mixed with the grist (one handful in summer, two in winter). The mash is fermented in a wooden vessel for 2-3 days in summer or 7 days in winter. After fermentation, water is added, and the mixture is strained through a bamboo basket to obtain *zutho*, an off-white

alcoholic slurry with approximately 5% alcohol, pH 3.6, and acidity 5.1 (Teramoto *et al.*, 2002) ^[51]. Similarly, the Zeme Naga tribe of North Cachar Hills, Assam, prepares a comparable beverage called dekuijao (Chakrabarty *et al.*, 2009).

(d) Judima: *Judima* is a traditional rice beer prepared by the Dimasa tribe of Assam, using a starter culture called *humao* (Chakrabarty *et al.*, 2009). To prepare *humao*, brown rice is soaked for 10-12 hours at room temperature, crushed with the barks of *Glycyrrhiza glabra* L., mixed with water to form a paste, and shaped into flat cakes which are then sun-dried. For brewing *judima*, rice is cleaned, washed, cooked, and dewatered, then cooled and mixed thoroughly with an appropriate amount of *humao*. The mixture is spread on a banana leaf overnight and then transferred to an earthen pot, partially sealed for fermentation. Fermentation occurs at ambient temperature for 3-4 days in summer or 6-7 days in winter. The resulting liquid, rich in alcohol, is known as *judima* (Chakrabarty *et al.*, 2009).

(e) Chubitchi: The Garos, a Tibeto-Burman community residing in the Garo Hills of western Meghalaya, traditionally prepare a rice beer called *Chubitchi*. Its starter culture, known as Wanti, is made by soaking sticky rice (*Menil*), optionally adding red chilies, and grinding it with plant leaves into small dough balls, sometimes incorporating charcoal for a smoky flavor. The doughs are wrapped in jackfruit leaves and left in bamboo baskets at room temperature for 6-7 days to dry. For brewing, cooked rice is cooled, mixed with Wanti, and packed in a bamboo basket sealed with banana or ficus leaves. Charcoal and chilies may be added atop the basket as a cultural practice to ward off evil spirits. Fermentation takes 6-15 days depending on temperature, yielding the aromatic and culturally significant beverage, *Chubitchi* (Mishra *et al.*, 2021) ^[25].

(f) Kiad: *Kiad*, a traditional fermented rice beverage, is commonly consumed by both the Khasi and Pnar communities of Meghalaya during various religious ceremonies and festivals. While moderate consumption is considered beneficial for health and traditionally used to alleviate ailments such as urinary disorders and dysentery, excessive intake may be harmful or toxic. The preparation begins with the creation of a starter cake, in which powdered local red rice is mixed with spring water and powdered plant parts to form a sticky paste. Small dough pieces are shaped from this paste and allowed to dry completely. For brewing, the rice is cooked with spring water in a metallic vessel, and once cooled and dried, it is combined with the yeast cake. The mixture is then fermented for three to four days before being boiled in a specialized vessel called a *set-kiad* to produce the final traditional beverage (Mishra *et al.*, 2021) ^[25].

3. Fermented vegetables

(a) Sinki: *Sinki* is a traditional fermented radish (*Raphanus sativus* L.) taproot, consumed by Nepalis in Darjeeling, Sikkim, and Nepal. It is prepared during the winter months, when the weather is least humid and radishes are plentiful. The fermentation is driven by *Lactobacillus plantarum*, *L. brevis*, and *L. fermentum* (Tamang and Sarkar, 1993). Fresh radish roots are washed, wilted under the sun for 1-2 days, shredded, soaked in lukewarm water, squeezed, and tightly packed into an earthen jar, which is then sealed and covered

with radish leaves. The jar is kept in a warm, dry place for 15-30 days. Alternatively, a pit about 1 m deep is prepared, lined with dried leaves and plastered with hot mud, and the shredded roots are pressed tightly inside. The pit is covered and left to ferment for 30-40 days. After fermentation, the radish mass is cut into pieces and sun-dried for 3-5 days. Properly stored, *Sinki* can last for over two years at room temperature with periodic exposure to sunlight (Tamang and Sarkar, 1993).

(b) Ziang-sang/ Ziang-dui: *Ziang-sang* is a traditional fermented leafy vegetable widely consumed in Manipur and Nagaland, predominantly prepared by Naga women and sold in local markets (Tamang and Tamang, 2009a) ^[39]. It is made from 2-3 days old withered leaves of *hangam* (*Brassica* sp.), which are crushed using a wooden mortar and pestle, soaked in warm water, and squeezed to remove excess moisture. The leaves are then packed into an airtight container for semi-solid fermentation at ambient temperature (20-30 °C) for 7-10 days. The resulting product is separated into two forms: the solid paste, sun-dried for 4-5 days and storable for over a year, is called *Ziang-sang*, while the liquid portion is concentrated by boiling and stored in bamboo containers as *Ziang-dui*. The fermentation is driven by *Lactobacillus plantarum*, *L. brevis*, and *Pediococcus acidilactici* (Tamang *et al.*, 2005). *Ziang-sang* is typically consumed as a soup with boiled rice, whereas *Ziang-dui* is used as a condiment alongside meals (Jeyaram *et al.*, 2009) ^[14].

(c) Anishi: This traditional fermented product from Nagaland, prepared mainly by the Ao tribe, is made using edible yam (*Colocasia* sp.) leaves. Fresh mature leaves are collected, washed, stacked, and wrapped in a banana leaf, then left to ferment for 6-7 days until yellowed. The yellowed leaves are combined with salt, chili, and ginger, ground into a paste, and shaped into cakes, which are dried over a fireplace for 2-3 days. The product is used as a condiment, commonly cooked with dried meat, especially pork (Mao and Odyuo, 2007).

4. Fermented Soyabean: The practice of consuming naturally fermented soybeans is widespread among various ethnic groups across Oriental countries, including the Himalayan regions of India, Nepal, and Bhutan (Tamang, 2010).

(a) Tungrymbai: A fermented soybean dish commonly consumed as a side dish in Meghalaya, India (Tamang *et al.*, 2009) ^[39]. Its preparation involves washing and soaking local soybean varieties for 4-6 hours, followed by dehulling through gentle rubbing. The beans are then boiled for 1-2 hours until they become soft and most of the water evaporates. After cooling, the beans are wrapped in leaves of *Clinogyne dichotoma* or *Phrynium pubinerve*, placed in a bamboo basket, and covered with a thick cloth or jute sack. The basket is kept near a fireplace, maintaining a temperature of 25-40 °C, where the beans ferment naturally for 3-5 days, resulting in a sticky, flavorful product. The fermentation of *Tungrymbai* is primarily carried out by *Bacillus subtilis*, along with *B. licheniformis*, *B. pumilus*, and minor populations of *Lactobacillus plantarum* and *Candida* spp., which contribute to its characteristic texture, flavor, and alkaline nature (Thapa & Tamang, 2004) ^[55].

(b) Bekang: It is a traditional fermented sticky soybean product from Mizoram, India (Tamang *et al.*, 2009). To prepare it, small yellow soybeans are first soaked overnight and then boiled for 1-2 hours until soft. The cooked beans are spread on a bamboo tray or basket lined with leaves of *Callicarpa arborea* or *P. pubinerve*. A small amount of firewood ash is sprinkled over the beans before covering them with the same leaves and a soft cloth. The tray is then placed near a fireplace, where natural fermentation takes place at 25-40 °C for about 3-4 days. The fermentation of *Bekang* is dominated by *Bacillus subtilis*, along with species such as *B. licheniformis* and *B. pumilus*, which bring about protein degradation and the development of its sticky texture and characteristic flavor (Thapa & Tamang, 2004).

(c) Hawaijar: *Hawaijar* is a traditional fermented soybean product of Manipur, valued for its distinct flavor and aroma. Locally grown small-sized soybeans are cleaned, shade-dried, soaked overnight, and then boiled until soft. The excess water is drained, and the beans are rinsed with tap water before being packed in *Ficus hispida* (fig) leaves. They are kept inside a bamboo basket for fermentation, which typically lasts 4-5 days in winter and 2-3 days in summer. The product is considered ready when sticky, slimy white substances appear along with a strong ammoniacal smell. The preparation process follows the methods reported by Premarani & Chhetry (2011) and Keishing *et al.* (2015)^[15]. The fermentation of *Hawaijar* is predominantly driven by *Bacillus subtilis*, with occasional presence of *B. licheniformis* and *B. pumilus*, which hydrolyze soybean proteins and impart its characteristic sticky texture, strong aroma, and alkaline flavor (Thapa & Tamang, 2004).

(d) Kinema: *Kinema* is a traditional soybean-based fermented food made from *Glycine max*, locally called *bhatmas*, using “yellow” and “dark brown” cultivars. It is mainly prepared at the household level by the Limboo and Rai communities of Sikkim and sold in local markets. The product is sticky, with an ammoniacal flavour, and its preparation skills are passed down generations (Tamang *et al.*, 2009). Fermented soybean products are not only easily digestible but are also reported to promote health, help prevent diseases, and contribute to longevity (Singh *et al.*, 2009)^[36]. Fermentation occurs naturally, primarily involving *Bacillus subtilis* and *Enterococcus faecium*, while fungi such as *Candida parapsilosis* and *Geotrichum candidum* are also reported in commercial samples (Sarkar *et al.*, 1994)^[31]. For preparation, soybeans are soaked overnight, boiled, lightly ground to split cotyledons, and mixed with about 1% firewood ash to maintain alkalinity. The grits are placed in a bamboo basket lined with fresh fern, covered, and fermented at 20-35 °C for 1-2 days. Fermentation is complete when a white sticky mass and ammoniacal odour appear. Shelf life is short-2-3 days in summer and 5-7 days in winter (Tamang *et al.*, 2009)^[39]. Traditional practice avoids washing the mortar and pestle, helping preserve microbes for spontaneous fermentation without starter cultures (Tamang, 2003).

(e) Axone/Akhuni: *Axone* (also spelled *Aakhone*) is a traditional fermented soybean product from Nagaland, characterized by a sticky, paste-like consistency and an umami flavor, which is slightly alkaline with an ammoniacal aroma. (Singh *et al.*, 2009)^[36]. *Axone* is prepared using

locally available soybeans. The process typically involves cleaning, soaking, dehulling with a wooden pestle and mortar, boiling for around 30 minutes, and then grinding with a wooden pestle and mortar. The ground soybean is then wrapped in banana or bamboo leaves in 50-100 g packets and left to ferment above a kitchen fire at a height of 1-2 meters for 3-7 days, depending on the weather. Fresh *axone* is ready when fermentation produces a sticky, stringy, lemon-colored product. For maturation, unopened packets are kept in smoke-filled kitchen areas for several weeks. Dried *axone* is obtained from matured *axone* after 1-2 months of storage, ground, and stored in airtight glass jars for use as a curry powder (Singh *et al.*, 2009)^[36]. Consumption of *axone* and *axone*-like fermented soybean products is claimed to be associated with several health benefits despite their very peculiar smell (Tamang, 2010)

(f) Peru yaan: *Namsing peru*, also known as *Peru yaan* or *Peha* in Apatani or Nyishi, is a fermented soybean. Mature *Glycine max* (L.) Merr. (Soybean) It is washed and then boiled in water for one to two hours. The excess water is drained out of the boiling beans by transferring them to a bamboo sieve known as *Ophi* (in Nyishi). After that, it is stored in an airtight container and left in the sun or over the fireplace to ferment. The freshly made *Namsing peru*/*Peru yaan*/*Peha* is mixed with the starter culture to speed up fermentation. In summer, the full fermentation process takes three to four days, while in winter, it takes two to three weeks (Bhardwaj *et al.*, 2024)^[5].

5. Fermented fish

(a) Ngari: *Ngari* is a traditional fermented fish from Manipur, made from sun-dried *Puntius sophore*, *Puntius ticto*, and *Setipinna* species, fermented 5-6 months in earthen pots (Taorem & Sarojanlini, 2012)^[49]. Consumed as a side dish (*Ironba*) or in *Eromba*, it has a 12-18 months shelf life and is important in local festivals (Singh *et al.*, 2018, 2019). Sun-dried *Puntius sophore* is rinsed in bamboo baskets and drained for 24-48 hours (Keishing & Banu, 2015). Excess water from the head and bones is pressed out, which may initiate fermentation (Jeyaram *et al.*, 2009)^[14]. Earthen pots (Kharung) are coated with mustard oil to create an anaerobic environment; new pots require 8-10 coatings at 7-10 days intervals (Keishing & Banu, 2015). Pressed fish is placed in the pot, sealed with mud or clay, and stored at room temperature for 6-12 months (Jeyaram *et al.*, 2009)^[14]. The top layer of fish (phumai) is less valued, while the inner content, *Ngari*, sells for Rs 500-600/kg and is widely consumed across Northeast India and Myanmar (Singh *et al.*, 2019). The fermentation of *Ngari* is mainly carried out by *Bacillus subtilis*, *Bacillus licheniformis*, and *Bacillus pumilus*, along with *Staphylococcus spp.* and *Micrococcus spp.*, which contribute to protein hydrolysis, flavor development, and preservation during long-term fermentation (Taorem & Sarojanlini, 2012)^[49].

(b) Hentak: *Hentak* is a traditional fermented fish paste from Manipur, made using a combination of sun-dried fish powder and aroid plant petioles. Small fish, specifically *Esomus danricus*, are thoroughly washed, sun-dried, and ground into a powder. The petioles of *Alocasia macrorrhiza* are chopped, washed, and left in the sunlight for one day. Equal quantities of the fish powder and prepared petiole pieces are then mixed to form a thick, ball-like paste, which

is placed in an earthen pot, sealed tightly, and allowed to ferment for 7-9 days. *Hentak* is typically used as a curry ingredient or condiment and is sometimes given to women in the late stages of pregnancy or to patients recovering from illness or injury. Thapa, 2016^[54].

(c) Tungtap: *Tungtap* is a traditional fermented fish of the Khasi tribe in Meghalaya, prepared at the household and village level and sold mainly in weekly markets (Sekar & Mariappan, 2007)^[33]. Its microbial community includes *Lactobacillus coriniformis*, *L. lactis*, *L. fructosus*, *Bacillus cereus*, *B. subtilis*, *Candida* sp., and *Saccharomycopsis* sp. (Thapa et al., 2004). *Puntius sophore* fish are cleaned, salted, and placed in a clay pot with a salt-fish/pork fat mixture. The pot is covered with a banana leaf, tied with jute, and left at room temperature for 6-7 months. After fermentation, excess salt and fat are removed before consumption (Agrahar-Murungkar & Subbulakshmi, 2006)^[1].

(d) Ngiiyi: The Apatani community produces *Ngiiyi yaan*, a traditional fermented fish product consumed either as a chutney or incorporated into curry dishes. The preparation involves thoroughly cleaning and washing fresh fish, mixing it with salt, and storing it in an airtight container for approximately one week to allow fermentation. After fermentation, it is typically served with boiled rice (Bhardwa et al., 2024).

(e) Shidal: *Shidal* is a salt-free, semi-fermented fish product from Northeast India, reddish-brown in color (Muzaddadi & Mahanta, 2013). It is made from *Puntius* sp. (*Puntius sophore*) or the estuarine fish *Setipinna phasa* (Majumdar et al., 2016) and is known by different regional names: seedal, seepa, hidal, shidol, and Ngari in Manipur (Ahmed et al., 2016). The fish remains mostly intact, with slight disintegration near the belly and tail (Majumdar et al., 2016). *Shidal* is consumed daily in dishes like *shidal* chutney (noted for malaria-curing properties), *mosdeng*, *ghodak*, and *berma butui* (Uchoi et al., 2022). *Shidal* Semi-dried *Puntius* sp. is used for *Shidal*, as partial drying allows microorganisms to initiate fermentation (Ahmed et al., 2016). Clay pots (*matka*) smeared with oil for 2-10 days are used for fermentation (Majumdar et al., 2016)^[19]. The dried fish is cleaned, soaked in water (duration depends on fermentation time), and packed into the *matka* (35-37 kg per 40 kg pot). Fermentation occurs at room temperature for 3-6 months. Freshly opened *Shidal* is dull white, turning from light to deep brown upon exposure to air (Majumdar et al., 2009)^[19]. To preserve flavor, 5% salt is added, and the product is wrapped in paper or polythene for sale (Mahanta & Muzaddadi, 2012). *Shidal* is widely consumed by various tribes in dishes like *Godak*, *Shidal* chutney, and *Chakhoe* (Uchoi et al., 2015)^[60]. A similar process is followed for *Ngari* in Manipur, with variations in naming and maturation time.

(f) Godak: *Godak* is a semi-fermented, unsalted fish product made from uncooked *Shidal* (Thapa, 2016)^[54]. It has a strong odor that may be off-putting initially. For *Godak*, fresh *Puntius Shidal* is cleaned and set aside. Vegetables like beans, green peas, green chilies, banana stems, bamboo shoots, and potatoes are washed, chopped, and boiled in a round-bottomed aluminum container (*dekchi*) for about 30 minutes. The *Shidal* is then added and boiled further. After cooling slightly, the mixture is mashed

with a bamboo stick to produce *Godak*, which has a semi-solid consistency (Dhar et al., 2012)^[10].

6. Other fermented foods

(a) Kharoli: *Kharoli* is a traditional fermented chutney made from mustard seeds (*Brassica juncea* or *B. nigra*) in Assam. The seeds are washed, dried, ground, and sieved, then placed on the dorsal side of a banana (*Musa* sp.) leaf warmed over a fire. Salt and *kolakhar* (indigenous soda) are gradually added while kneading the mixture for about 15 minutes. The mass is shaped into flattened balls, wrapped in the leaf, tied with a string, and kept in a warm place for around three days. The resulting chutney, *kharoli*, is sour and commonly eaten with rice in Assam (Hughes et al., 2001)^[12].

(b) Kodo ko Jaanr: The tribal people of Sikkim prepare *Kodo ko Jaanr* from dry seeds of finger millet (*Eleusine coracana*), locally called *kodo*, which is an important part of their dietary and religious practices (Tamang et al., 1996; Sekar and Mariappan, 2007)^[33]. A traditional mixed starter culture called *murcha* is used, containing a variety of microbes such as *Mucor cicinelloides*, *Rhizopus chinensis*, *R. stolonifer* var. *lyococcus*, *Saccharomyces cerevisiae*, *S. bayanus*, *Hansenula anomala*, *Pediococcus pentosaceus*, *Lactobacillus* sp., and several other yeasts and fungi (Tiwareti et al., 2007)^[58]. *Murcha* is prepared by soaking and pounding glutinous rice, mixing it with roots, leaves, flowers, ginger, red chili, and previously made *murcha*, shaping into cakes, fermenting for 1-3 days, and sun-drying for 2-3 days. The dried *murcha* can be stored for more than a year (Tsuyoshi et al., 2005)^[59]. For making *Kodo ko Jaanr*, finger millet is cleaned, cooked, cooled on a bamboo mat (*mandro*), and sprinkled with 1-2% powdered *murcha*. The mixture is packed in baskets lined with fresh ferns or banana leaves, covered, and fermented for 2-4 days at room temperature, followed by 3-7 days depending on the season in earthen pots or bamboo baskets. The fermented mass is mixed with lukewarm water in a vessel (*toongbaa*) to extract the drink, which is sipped through a bamboo straw (*pipsing*), adding water 2-3 times to obtain more extract (Singh and Jain, 1995; Tamang et al., 1996).

(c) Pila/Taache/Chola: Known as *Pila* among the Apatani and *Taache* or *Chola* among the Nyishi, this alkaline liquid is locally recognized as *Khar*. It is commonly prepared from plants such as *Carica papaya* L., *Musa* sp., and *Eleusine coracana* L. For its preparation, the plants are cut into pieces and dried either under sunlight or over a fire to eliminate moisture. The dried material is then roasted or burnt, and the resulting ashes are collected. These ashes are placed in a bamboo funnel, called *sadar* (in Apatani), through which cold water is slowly poured to extract the liquid. The filtrate obtained, termed *Pila/Taache/Chola*, is alkaline in nature and traditionally used as a flavouring component in various bamboo-based cuisines (Bhardwaj et al., 2024)^[5].

Discussion

Traditional fermented foods of Northeast India, including bamboo shoots, rice beverages, vegetables, soybeans, fish, and specialty items, reflect the region's rich ethnic, cultural, and ecological diversity. Bamboo shoots like *Soibum*, *Lung-siej*, and *Tuaitar* rely on LAB, *Bacillus* spp., and yeasts for

flavor, preservation, and digestibility, while rice-based alcoholic drinks such as *Hor*, *Apong*, and *Zutho* use locally prepared starter cultures to produce ethanol and enhance nutritional value. Fermented vegetables (*Sinki*, *Ziang-sang*) and soybean products (*Kinema*, *Axone*, *Peru yaan*) demonstrate traditional knowledge in controlling fermentation through temperature, moisture, and natural inoculum, yielding foods that are safe, nutritious, and culturally significant. Fermented fish (*Ngari*, *Hentak*, *Shidal*) employs sun-drying, salting, and anaerobic storage for preservation and flavor development. Other products like *Kharoli* and *Kodo ko Jaanr* showcase the use of local plants, grains, and alkaline extracts in fermentation. Overall, these foods exemplify the integration of microbial diversity, indigenous techniques, and cultural practices, providing nutritional benefits, long shelf life, and opportunities for sustainable livelihoods while preserving traditional knowledge.

Conclusion

The traditional fermented foods of Northeast India epitomize the intricate relationship between culture, ecology, and microbiology. From bamboo shoots and rice-based beverages to vegetables, soybeans, and fish products, these foods reflect the region's rich ethnic diversity and centuries-old culinary heritage. Fermentation practices harness naturally occurring microbes such as Lactic Acid Bacteria, *Bacillus* species, and yeasts, enhancing flavor, digestibility, and nutritional quality while ensuring preservation. Starter cultures, controlled fermentation conditions, and local ingredients demonstrate sophisticated indigenous knowledge, allowing communities to produce safe and functional foods. Beyond their nutritional and sensory value, these fermented products hold socio-cultural significance, supporting festivals, rituals, and daily diets, while contributing to sustainable livelihoods. Preserving and promoting these traditional practices not only safeguards biodiversity and microbial heritage but also provides potential avenues for developing functional foods, probiotics, and nutraceuticals, bridging traditional wisdom with modern food science. Traditional fermented foods of Northeast India represent a valuable reservoir of microbial diversity, indigenous knowledge, and nutritionally important food systems. Despite their cultural and dietary significance, many of these products remain underexplored from scientific and technological perspectives. Future research should focus on the comprehensive characterization of microbial communities involved in fermentation using advanced molecular techniques such as metagenomics and next-generation sequencing. Such approaches will help identify dominant functional microorganisms, understand microbial succession during fermentation, and reveal potential probiotic strains with health-promoting properties.

Authors' contributions

Ngayaipam Zimik conceptualized and designed the review. Hunmely Englengpi and Jennyferjune Ronghangpi collected and analyzed the literature. All authors contributed to the interpretation of findings and critical revision of the manuscript. All authors read and approved the final manuscript.

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