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Research Article

Indigenous Fermented Foods of North Bengal, India: A Comprehensive Review of Microbiota, Nutritional Enrichment, And Health-Promoting Potential

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Abstract

The Eastern Himalayan region of North Bengal, India, a melting pot of diverse ethnicities and traditions, harbours a rich and underexplored repository of indigenous fermented foods and beverages. These products, spanning categories of dairy, cereals, vegetables, bamboo shoots, and meats, are not merely dietary staples but are deeply intertwined with the socio-cultural and medicinal fabric of the local communities. Driven by spontaneous or back-slop fermentation, these foods host a complex consortium of lactic acid bacteria (LAB), yeasts, and acetic acid bacteria, which are the key architects of their unique organoleptic properties, bio-preservation, and health-promoting attributes. This comprehensive review systematically catalogues the predominant fermented foods of North Bengal, including Chhurpi (dairy), Kinema (soybean), Gundruk and Soidon (vegetables/bamboo), Kodo ko Jaanr or Chhang (finger millet beer), and various fermented fish products. We delve into the microbial ecology that underpins these fermentations, highlighting the dominant role of genera such as *Lactobacillus*, *Pediococcus*, *Leuconostoc*, and *Saccharomyces*. The paper critically evaluates the biotransformation occurring during fermentation, which enhances the bioavailability of nutrients, reduces anti-nutritional factors, and generates bioactive compounds like peptides, exopolysaccharides, and vitamins. The health perspectives, including improved gastrointestinal health through probiotics, enhanced antioxidant capacity, antihypertensive potential, and implications for metabolic and immune health, are discussed in detail. Furthermore, the review identifies challenges such as the lack of standardized industrial production, the threat of cultural erosion, and the need for robust clinical validation of health claims. It concludes by emphasizing the immense potential of these traditional foods as a source of novel probiotics and functional ingredients for the global health food market, advocating for a synergistic approach that integrates traditional knowledge with modern food science for sustainable development.

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INTRODUCTION

Fermentation is one of the oldest and most economical methods of food preservation and processing, dating back millennia. In regions with limited access to refrigeration and modern preservation technologies, fermentation has been indispensable for ensuring food security, enhancing shelf-life, and improving the nutritional value of perishable raw materials (Tamang et al., 2020). Beyond its utilitarian roles, fermentation is a cultural artifact, with techniques and recipes passed down through generations, forming an integral part of a region's gastronomic identity.

North Bengal, comprising the districts of Darjeeling, Kalimpong, Jalpaiguri, Cooch Behar, Alipurduar, and the Malda and Uttar Dinajpur, is a unique biogeographic zone. It is characterised by the terai (lowlands) and the dooars (foothills), which merge into the mighty Himalayas. This region is home to a diverse populace, including the indigenous Rajbanshi, Lepcha, and Limbu communities, as well as the Gorkhas of Nepali origin, among others. Each community has contributed to a rich tapestry of culinary practices, with fermentation playing a central role (Thapa, 2016).

The fermented foods of this region are remarkably diverse, ranging from acidic vegetable pickles and pungent fish products to alcoholic cereals and unique dairy preparations. While some, like Kinema, are shared with the broader Eastern Himalayan belt, others possess distinct local characteristics. Despite their local prominence and purported health benefits, a systematic scientific consolidation of their microbial profiles, biochemical transformations, and validated health effects remains fragmented.

This comprehensive review, therefore, aims to:

1. Systematically document the major indigenous fermented foods of North Bengal.
2. Elucidate the microbial consortia responsible for their fermentation.
3. Analyze the nutritional and bioactive changes occurring during the fermentation process.
4. Critically review the scientific evidence supporting their health-promoting potential from a biochemical and microbiological perspective.
5. Discuss the challenges and future prospects for the scientific validation and sustainable commercialization of these traditional functional foods.

1. Major Indigenous Fermented Foods of North Bengal: A Taxonomic Overview

The fermented foods of North Bengal can be broadly classified based on their substrate.

1.1. Fermented Cereal-Based Beverages: Kodo ko Jaanr/Chhang and Others Alcoholic beverages prepared from cereals are central to the social and religious life of many North Bengal communities. Kodo ko Jaanr or Chhang is a traditional, mildly alcoholic, sweet-sour beverage prepared from finger

millet (*Eleusine coracana*) (Das et al., 2016). The production involves cooking the millet, inoculating it with a traditional starter culture called Marcha or Manapu, and allowing it to ferment in a earthen vessel for several days. The resulting product is consumed in a semi-liquid form, often with added water. Similar beverages are made from rice (Jaanr), barley, and other local grains. Marcha itself is a complex consortium of molds (*Mucor*, *Rhizopus*), yeasts (*Saccharomyces*, *Pichia*), and LAB, encapsulated in a dough-ball form, representing a remarkable example of traditional biotechnology (Chettri & Tamang, 2015).

1.2. Fermented Soybean Products: Kinema

Kinema is a sticky, alkaline, and pungent-smelling fermented soybean product, a staple protein source in the Himalayan diet. Although more widely studied in Sikkim and Nepal, its consumption is prevalent in the Darjeeling hills and the surrounding areas of North Bengal. Whole soybeans are cleaned, soaked, boiled until soft, and crushed slightly before being inoculated with a small amount of previous batch (back-slop) or with natural microbiota. After fermenting for 1-3 days in a warm place wrapped in leaves or cloth, a sticky texture and characteristic odor develop. *Bacillus subtilis* is the predominant microorganism, responsible for producing extracellular enzymes that hydrolyze proteins to peptides and amino acids (generating ammonia and the alkaline pH) and fats to free fatty acids (contributing to the flavor) (Sarkar & Tamang, 1995).

1.3. Fermented Vegetable and Bamboo Shoot Products:

Gundruk, Soidon, and Mesu

This category represents a crucial method for preserving seasonal vegetables for year-round consumption.

Gundruk: This is a fermented, dried, and acidic leafy vegetable product. Mustard, radish, and cauliflower leaves are wilted, shredded, pressed tightly into airtight containers, and allowed to undergo natural lactic acid fermentation for about 7-15 days. The fermented leaves are then sun-dried and stored. It is used as a condiment or in soups, imparting a distinctive sour flavor (Tamang et al., 2005).

Soidon: A similar fermentation process is applied to the tip of a succulent bamboo shoot (*Chimonobambusa callosa*). The shredded shoots are fermented in a container, producing a sour, pungent product used in curries and pickles (Tamang & Tamang, 2009).

Mesu: This is a traditional fermented bamboo shoot product, similar to soidon, but often prepared with specific practices leading to a different microbial profile, dominated by *Lactobacillus plantarum* and *Pediococcus pentosaceus*.

1.4. Fermented Dairy Products: Chhurpi and Dahi

Chhurpi: Two types of Chhurpi are prevalent. Soft Chhurpi is a fresh, cheese-like product made by curdling cow or yak milk

with lactic acid, followed by draining the whey. It is consumed as a snack. Hard Chhurpi is made by further boiling and drying the soft variety, resulting in a rock-hard product that is chewed as a longevity snack. It is an excellent source of protein and calcium (Dewan & Tamang, 2007).

Dahi: This is the ubiquitous Indian yogurt, prepared by fermenting boiled milk with a previous culture. It is a daily part of the diet, consumed plain, with rice, or in preparations like Lassi.

1.5. Fermented Fish Products: Shidal and Sukuti

In the terai regions of North Bengal, fermented fish is a common source of protein and flavouring. Shidal is a highly pungent, paste-like fermented fish product, typically made from small fish like *Puntius* spp. The fish are heavily salted, packed in earthen pots, and fermented for several months. Sukuti refers to sun-dried, often partially fermented, fish. These products are characterised by a strong odour and are used sparingly in curries to impart a deep umami flavor (Majumdar et al., 2016).

2. The Microbial Ecology of Fermentation

The fermentation of these diverse foods is driven by a succession of microorganisms that originate from the raw materials, the environment, or the traditional inocula. Lactic Acid Bacteria (LAB) are the undisputed workhorses in most of these processes.

2.1. Lactic Acid Bacteria (LAB): Species from the genera *Lactobacillus* (e.g., *L. plantarum*, *L. casei*, *L. brevis*), *Pediococcus* (*P. pentosaceus*), *Leuconostoc* (*L. mesenteroides*), and *Enterococcus* are frequently isolated from Gundruk, Soidon, Mesu, and Dahi (Tamang et al., 2005). Their primary role is the homofermentative or heterofermentative conversion of sugars into lactic acid, which acts as a natural preservative by lowering the pH and inhibiting spoilage organisms and pathogens. They also produce acetic acid, ethanol, and carbon dioxide, contributing to the flavor and texture profile.

2.2. Bacillus spp.: *Bacillus subtilis* is the key organism in Kinema fermentation. Its robust enzymatic activity, including proteases and amylases, is responsible for the extensive breakdown of macromolecules, leading to the product's unique texture and bioavailability of nutrients (Sarkar et al., 1994).

2.3. Yeasts and Molds: Yeasts such as *Saccharomyces cerevisiae*, *Pichia anomala*, and *Candida* spp. play a crucial role in alcoholic fermentations like Kodo ko Jaanr. They produce ethanol and a wide range of esters and higher alcohols that define the beverage's aroma. Molds like *Mucor* and *Rhizopus* are present in the starter culture Marcha, where they produce amylolytic enzymes to break down starch into fermentable sugars for the yeasts (Chettri & Tamang, 2015). This complex microbial consortium acts in a synergistic manner, creating a stable microbial ecosystem that ensures the

safety, preservation, and organoleptic quality of the final product.

3. Biotransformation and Nutritional Enhancement

Fermentation is not merely preservation; it is a process of biochemical refinement that significantly enhances the nutritional profile of the raw substrate.

3.1. Enhancement of Bioavailability: In cereal and legume-based foods like Kinema, fermentation reduces anti-nutritional factors such as phytic acid, which chelates minerals like iron and zinc. The reduction of phytic acid through microbial phytase activity significantly improves the bioavailability of these essential minerals (Reddy & Pierson, 1994). Similarly, complex proteins are hydrolyzed into peptides and free amino acids, making them more digestible.

3.2. Synthesis of Bioactive Compounds:

Bioactive Peptides: The proteolytic activity of LAB and *Bacillus* spp. during the fermentation of milk (Dahi), soybeans (Kinema), and fish can release bioactive peptides with demonstrated ACE-inhibitory (antihypertensive), antioxidant, and immunomodulatory activities (Sanjukta et al., 2015).

Exopolysaccharides (EPS): Some LAB strains produce EPS, which act as natural prebiotics, stimulating the growth of beneficial gut bacteria. They also contribute to the desired rheological properties, such as the viscosity and ropiness of Dahi.

Vitamins: Fermentation can increase the content of certain B vitamins (e.g., folate, riboflavin) due to microbial synthesis. For instance, Kinema has been reported to have a higher riboflavin and vitamin B12 content compared to unfermented soybeans (Dahal et al., 2003).

3.3. Detoxification and Safety: The rapid acidification by LAB in vegetable fermentations inhibits the growth of spoilage bacteria and, critically, prevents the growth of pathogenic organisms like *Clostridium botulinum*. Furthermore, some studies suggest that fermentation can reduce the levels of certain natural toxins and allergens present in raw materials.

4. Health-Promoting Perspectives: Beyond Basic Nutrition

The consumption of these fermented foods is traditionally associated with good health and vitality. Modern science is beginning to provide a mechanistic basis for these age-old beliefs.

4.1. Probiotic and Gut Health Benefits: Many of the LAB strains isolated from Gundruk, Soidon, and Dahi have been shown to possess classic probiotic properties. These include acid and bile tolerance, adhesion to human intestinal epithelial cells, and antagonistic activity against gastrointestinal pathogens like *Salmonella* and *E. coli* (Tamang et al., 2016).

Regular consumption of these live microbes can help in maintaining a healthy gut microbiota balance, preventing diarrhea, and improving overall digestive health.

4.2. Antioxidant Potential: The fermentation process can liberate or synthesize compounds with potent antioxidant activity. For example, the hydrolysis of soybean isoflavones (daidzin, genistin) into their aglycone forms (daidzein, genistein) during Kinema fermentation significantly enhances their free radical scavenging capacity (Ishikawa, 2015). Similarly, fermented vegetable products show increased antioxidant activity compared to their unfermented counterparts.

4.3. Antihypertensive and Cardio-Protective Effects: The ACE-inhibitory peptides generated during the fermentation of milk (Dahi) and soybeans (Kinema) have been demonstrated in vitro and in animal models to lower blood pressure. The cholesterol-assimilating property of certain LAB strains, combined with the general improvement in lipid profiles associated with fermented food consumption, points to a potential cardio-protective role (Sonestedt et al., 2011).

4.4. Immunomodulation and Anti-cancer Potential: Components of the fermented foods, including bacterial cell wall fragments (peptidoglycan), EPS, and bioactive peptides, can interact with the host's immune system, potentially enhancing innate and adaptive immune responses. Some studies on fermented soy products have suggested a correlation between their consumption and a reduced risk of certain cancers, although this area requires more extensive and targeted research (Wong et al., 2020).

5. Challenges and Future Perspectives

Despite their immense potential, the traditional fermented foods of North Bengal face significant challenges.

5.1. Standardization and Safety: The traditional production is largely artisanal, leading to batch-to-batch variations in quality, flavor, and microbial load. There is a risk of contamination with undesirable microbes, including mycotoxin-producing molds, if hygiene is not maintained. Developing defined starter cultures with selected, safe, and potent strains is crucial for standardization and scaling up production.

5.2. Scientific Validation and Clinical Trials: While in-vitro and animal studies provide promising evidence, there is a stark lack of robust, randomized, placebo-controlled human clinical trials to substantiate the specific health claims associated with these foods.

5.3. Cultural Erosion and Knowledge Preservation: With urbanisation and changing dietary habits, the knowledge of preparing these traditional foods is at risk of being lost.

Documenting and preserving this intangible cultural heritage is as important as its scientific study.

5.4. Commercialisation and Geographical Indication (GI):

There is a significant opportunity for the commercial production of these foods, which could boost the local economy. Securing Geographical Indication (GI) tags for unique products like Kinema or specific types of Chhurpi can help protect their identity and add economic value.

The future lies in a synergistic approach where traditional knowledge (ethno-microbiology) is combined with modern tools of genomics, metabolomics, and food engineering. This will allow for the isolation and characterization of novel probiotic strains, optimization of fermentation processes for enhanced bioactivity, and the development of these indigenous foods into validated, market-ready functional foods for a global audience.

CONCLUSION

The indigenous fermented foods of North Bengal represent a remarkable legacy of traditional food biotechnology. They are not just sustenance but are complex, dynamic systems where microbial activity transforms simple raw materials into nutritionally enhanced, safe, and flavorful products with significant health-promoting potential. The dominant microbial populations, primarily LAB and yeasts, drive biotransformations that improve digestibility, generate bioactive compounds, and impart probiotic properties. The scientific evidence, though growing, strongly supports traditional claims regarding their benefits for gut health, antioxidant defense, and metabolic regulation. To fully unlock their potential, a concerted effort is needed to standardize production, conduct rigorous clinical research, and protect the associated traditional knowledge. By bridging the gap between traditional wisdom and modern science, these humble fermented foods from the foothills of the Himalayas can find a rightful place in the global pantheon of functional and health-promoting foods.

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