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Ethnic fermented foods and beverages of West Bengal: Microbial consortium and Health attributes

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ABSTRACT

Fermented foods are a vital component of West Bengal's culinary history, demonstrating its many cultural heritage and new ways of preparing meals. People have liked foods like Panta Bhat, Shidol, and Chal paneer for hundreds of years, not just because they taste good, but also since they are good for your gut health and nutrition. Fermentation is a natural process that makes essential substances like vitamins, minerals, and antioxidants accessible to the body to absorb. It also adds helpful microbes that assist in maintaining the stomach healthy. This review emphasises the range of traditional fermented meals in West Bengal, their nutritional characteristics, and the impact of microbial dynamics on their functional attributes. It also explores at the cultural importance and possible health benefits of these foods, such as better digestion, a stronger immune system, and the prevention of chronic diseases. Following these historic methods enables an incorporation of nutrient-dense, probiotic-rich foods into modern functional diets.

1. INTRODUCTION:

India became a country in 1947, when West Bengal broke apart from East Bengal and became part of India. West Bengal is a state in eastern India that is recognised for its extensive cultural heritage and an extensive variety of foods (Acharya et al., 2025). It is not easy to share the story of food. Owing to insufficient information regarding ethnic cuisine and culture. What precisely constitutes fermented foods? The term fermentation is derived from the Latin word "fevere," which means "to boil." Humans have utilized fermentation processes for centuries, significantly contributing to food production and preservation, while also enhancing flavor and nutritional value (Chilton and Reid 2015). Fermentation is among the oldest and most prevalent techniques for food preservation, deeply embedded in the culinary traditions of global societies. This natural process entails the metabolic functions of microorganisms, including bacteria, yeasts, and molds, which convert raw materials into food products with prolonged shelf life, enhanced flavors, and superior nutritional attributes (Tamang et al., 1988). In India, characterized by diverse climates and agricultural practices, fermentation is integral to both the daily diet and cultural heritage. Fermented foods, originating from the Himalayan mountainous region to the agricultural plains of West Bengal, are now closely associated with traditional dietary practices of nutritious consumption (Ghosh et al., 2022). These foods not only fulfil practical needs,

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nevertheless they also have big benefits, such as keeping perishable components fresh in the humid climate of eastern India as well as being good for the well-being of individuals.

West Bengal is known for its varied and rich food traditions, and it has a unique selection of fermented foods which demonstrate off its cultural and geographical uniqueness. People favour panta bhat (fermented rice), shidol (fermented fish), and gundruk (fermented leafy greens) since they taste tasty and are good for you (Roy et al., 2007). People frequently prepare these foods utilizing easy methods that come from conventional methods of cooking. The classic fermentation techniques use bacteria that are already in the food. These microbes not only keep the food from going bad, but they additionally contribute to it more nutritious by adding B vitamins, vital amino acids, and probiotics that help intestinal health (Manna, 2023). Many centuries-old ceremonies are having difficulty functioning since cities are growing, which means that people are relying more on commercial food production.

This review sought to fulfil three objectives in accordance with our intent. The main goal is to show off an array of traditional fermented treats from West Bengal and talk about their significance in history and culture. Additionally, it stresses the study of the nutrient profiles of these foods, which gives clues about their macronutrient and micronutrient content and the biologically active chemicals that create themselves during fermentation (Tamang et al., 2020). This review evaluates the health benefits of fermented foods, underlining their contribution to digestion improvement, immunity enhancement, and the decrease of chronic disease risks, such as diabetes and cardiovascular conditions (Hor et al., 2022). This review study seeks to reconcile traditional food knowledge with modern nutritional science, arguing for the continued preservation and growth of these essential culinary traditions.

2. Fermented foods of West Bengal:

India is distinguished by its diversity and terrain, with the small state of West Bengal surrounded by many rivers that are essential to a freshwater ecology and merge with the ocean. Dey and Panigrahi (2022) These are renowned for their variations in regional cuisines and dining customs. The eastern Indian state of West Bengal is located at 22.9868 ºN and 87.855 ºE. West Bengal comprises 23 districts, with the Southern Districts situated in plains and the Northern District located at the foothills of the Himalayas. It is renowned for its racial diversity and extensive cultural heritage. The rural areas of the state are primarily populated by Schedule Tribes. West Bengal is anticipated to have an estimated population of 99.72 million, ranking it as the fourth most populous state in India. In perspective, West Bengal's population parallels that of Vietnam, the 16th most populous nation globally. West Bengal has surpassed Tamil Nadu to become the fourth most populous state in India.

The 2011 Census indicates that there are 5,296,963 tribal individuals in West Bengal, constituting approximately 5.8% of the state's total population. Approximately fifty percent of all Scheduled Tribes (STs) comprise members of the Santal tribe, alongside significant populations of the Oraon, Munda, Bhumij, and Kora communities. The Tribal Development Department of the Government of West Bengal has indicated a substantial population of tribal residents in regions including Darjeeling, Alipurduar, Dakshin Dinajpur, Paschim Medinipur, Bankura, and Purulia. The state's ethnic groups can be categorized into four principal classifications: plains tribal groups (such as Santhal and Oraon), hilly tribal groups (including Bhutia, Lepcha, and Nepali), jungle mahal tribal groups (like Santhals and Majhi), and plains non-tribal groups (such as Bengali Hindus and Muslims, Biharis, and others). Each of these indigenous tribes and cultures possesses distinct customs. Fermented food products significantly influence the daily lives and social interactions of these civilizations (Voidarou et al., 2020). Additionally, certain households generate income by selling fermented food products. The fundamental elements of fermentation consist of various substrates. The principal agricultural products—grains, legumes, and seasonal fruits and vegetables—dictate the selection of substrate. These fermented delicacies are primarily produced and consumed by ethnic communities in their daily routines and are also utilized during special events and festivals. They serve as a crucial source of small-scale enterprises and income for numerous families. (Alam et al., 2024).

3. Overview of Common Fermented Foods:

3.1 Panta Bhat (Fermented Rice):

Panta Bhat, or water-soaked rice, is a fundamental fermented dish in rural West Bengal, especially favored by agrarian communities (Ray et al., 2016). In Bengali tradition, leftover rice from the previous day is immersed in water for fermentation overnight at ambient temperature. This straightforward procedure employs natural microorganisms, primarily lactic acid bacteria, which facilitate the decomposition of complex carbohydrates into simpler forms, resulting in the production of organic acids. Fermentation enhances the bioavailability of essential nutrients such as iron, calcium, and B-complex vitamins, which are not significantly present in raw rice (Hor et al., 2022). This dish can be complemented with onions, green chilies, and

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mustard oil, resulting in a nutrient-dense, easily digestible, and probiotic-rich meal. This uncomplicated yet nutritious food is celebrated for its cooling attributes, rendering it appropriate for the hot and humid climate of Bengal. Panta Bhat possesses cultural significance and is frequently highlighted in festivals like Pohela Boishakh (Bengali New Year) (Tamang, 2010).

3.2 Shidol (Fermented Fish):
Shidol, a fermented dried fish, is a significant traditional cuisine in the riverside and marshy areas of West Bengal (Behera et al., 2020). Shidol is a traditional fermented fish product, wherein Indian shad is preserved and fermented in sealed containers, allowing Bacillus species to facilitate the breakdown of proteins and lipids, resulting in a potent odor. It serves as an exceptional source of protein, omega-3 fatty acids, and essential amino acids, and is frequently paired with rice and dal. In protein-deficient diets, Shidol serves as a significant low-protein option that enhances digestive health and supplies energy. The conventional production technique aids in mitigating the waste of excess or smaller fish (Arumugam et al., 2023)

3.3 Gundruk (Fermented Leafy Greens):
Gundruk is a meal produced through fermenting leafy vegetables which include spinach, mustard greens, and radish leaves. While it originated from Nepal, it is also widely recognised within Nepalese community in West Bengal (Ghatani et al., 2024). During sun-drying, the leaves are placed in airtight containers for fermentation, during which lactic acid bacteria provide a sour flavour while improving the nutritional profile, especially elevating vitamin C and beta-carotene concentrations, therefore assuring their preservation. Gundruk is frequently employed in soups and as a flavour enhancer, improving both flavour and nutritional benefits. The increased fibre content facilitates digestion, while its antioxidants confer preventative health advantages (Ghimire et al., 2020). The fermentation method of Gundruk ensures the long-term preservation of greens for nutritional health benefits.

3.4 Chal Paneer (Fermented Rice Pancakes):
Chal Paneer, a fermented rice pancake, has become a part of Bengali dwellings for many centuries. Fermentation with indigenous yeast or a starter culture makes the rice batter. During fermentation, good microorganisms like Saccharomyces species make the batter taste more delicious and add more nutrients. These fermented pancakes are fluffy and light and soft. Folks often eat them with curries, chutneys, or on their own (Kumar et al., 2014). Chal Paneer is thought to be one of the best sources of carbohydrates since it gives you a steady flow of energy. People who are concerned about blood sugar levels may benefit from fermented rice because it has a decrease in glycaemic index. It also makes nutrients easier to digest and absorb, ensuring that even a simple dish like this is equally important as a balanced diet.

3.5 Chungdi (Fermented Milk):
Chungdi is a conventional fermented dairy product. It is a relatively unknown dish from the West Bengal culture. Raw milk must be fermented for the preparation, or a starting culture, like curd from an earlier batch, can be added. Lactococcus and Streptococcus species help with the fermentation process, which makes a thick, sour product that is similar to yoghurt but has various textures and flavours according to where you live. It is a complete supply of nutrients, giving you good protein, calcium, and probiotics that are extremely good for you. These beneficial bacteria not only make the gut healthier, but they also help with lactose digestion. This means that Chungdi may be a good dairy option for people who are mildly intolerant to milk proteins (Narzary et al., 2016). Chungdi is a healthy and energising snack many individuals often consume plain or with jaggery and fruits. The simple way of making Bengali traditional food and the substantial amount of nutrients show how smart it is to promote health and nutrition (Tamang et al., 2020).

4. Preparation Techniques of Fermented Foods in West Bengal:
Ingredients and Traditional Methods:
In West Bengal, preparing fermented dishes is easy because they use locally grown ingredients that have been successfully passed down through the generations for many years. This shows how imaginative people can be when it comes to preserving food, making it healthier, and giving it distinctive flavours.

4.1. Panta Bhat (Fermented Rice):
- **Ingredients:** Cooked rice, water.
- **Method:** Throughout the night, rice is prepared by immersing it in water at room temperature using moist heat. Historically, Eastern pots were frequently used in rural areas to keep the temperature stable and create the ideal environment for spontaneous fermentation. The rice contains the requisite microorganisms; no additional starter culture is employed. Tamang et al. (1988).
- **Outcome:** The overnight fermentation of rice yields a mildly sour flavor, a softer texture, and improved nutritional benefits. It is typically consumed with mustard oil, green chilies, raw onions, and optionally lemon and garlic to taste.

4.2. Shidol (Fermented Fish):
- **Ingredients:** Small fish (e.g., Indian shad), salt.

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- **Method:** All the fresh fish are meticulously cleaned, seasoned, and securely packed in bamboo containers or sealed earthenware jars. These containers are maintained in a low-light environment for anaerobic fermentation over a period of weeks or months. Meanwhile, microorganisms and natural enzymes decompose fish protein, transforming it into a paste-like substance with a distinctive aroma and rich nutrient content. Roy et al. (2007).
- **Outcome:** These processes extend the shelf life of the fish while enhancing its flavor. The final product is frequently utilized as a flavor enhancer, seasoning, or flavoring agent in curries and chutneys.

4.3. Gundruk (Fermented Leafy Greens):

- **Ingredients:** Mustard greens, spinach, radish leaves.
- **Method:** Rinsed leaves are placed in sunlight for one day to decrease moisture content, and then stored undisturbed for several days in a tightly sealed clay pot. Furthermore, weights are frequently positioned atop to establish a secure environment for anaerobic conditions. To enhance the fermentation process, traditional fermenters occasionally incorporate a small quantity of prior Gundruk as a starter culture. (Sha et al., 2013).
- **Outcome:** The product that is tangy, preserved, packed with of vitamins and fibre from foods is made. Gundruk may be stored for months and can be served in stews or soups or as a side dish on on its own.

4.4. Chal Paneer (Fermented Rice Pancakes)

- **Ingredients:** Rice flour, water, optional sugar or jaggery.
- **Method:** A batter is produced by mixing rice flour and water together. Then, the batter is let to ferment at room temperature. The duration of the process typically ranges from 8 to 12 hours, occasionally exceeding this timeframe, contingent upon the ambient conditions. Certain households add curd to batter to speed up the fermentation process. Ghosh et al. (2020).
- **Outcome:** The fermentation process renders the batter light and tangy. The mixture is subsequently poured onto a heated griddle and cooked into soft, spongy pancakes, frequently accompanied by vegetable curries or chutneys.

4.5. Chungdi (Fermented Milk):

- **Ingredients:** Raw milk, optional starter (previously fermented milk).
- **Method:** The fresh milk is heated to a boil at room temperature and subsequently permitted to cool. A small quantity of previously fermented milk or curd is blended and left undisturbed for 6 to 8 hours, or longer, to facilitate natural fermentation at a moderate temperature. Eastern pots are frequently utilized in rural regions to enhance mouthfeel. Narzary et al. (2016).
- **Outcome:** The milk undergoes fermentation, resulting in a tangy, viscous product akin to yogurt, albeit with regional variations. This chungdi is typically consumed with jaggery and fruits.

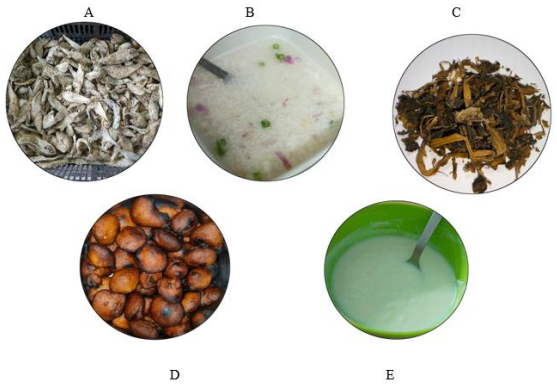

Fig.1. (A) ***Shidol (Fermented Fish);*** **(B)** ***Pantha Bhat (Fermented Rice);*** **(C)** ***Gundruk (Fermented Leaves);*** **(D)** ***Chal Paneer (Fermented Rice Pancakes);*** **(E)** ***Chungdi (Fermented Milk)***

5. Role of Microorganisms in Fermentation:

Naturally occurring microorganisms play a significant role in the production of these historical or cultural fermented foods. These microorganisms enhance the texture, flavor, and nutritional content of food, while also improving its shelf life during preservation. The significant microorganisms essential for the fermentation of traditional foods in West Bengal include.

5.1. Lactic Acid Bacteria (LAB):

It is the principal microorganism that metabolizes sugar into lactic acid, thereby reducing the pH. This acidification aids in food preservation and imparts a tangy flavor. The cuisine comprises panta bhat, gundruk, and chungdi. (Hor et al., 2022). LAB also contribute to the synthesis of B-complex vitamins and enhance mineral bioavailability.

5.2. Yeasts (Saccharomyces spp.):

Yeasts serve as the active agent in the fermentation of Chal Panner, decomposing sugars to produce carbon dioxide and ethanol. This method enhances digestion in pancakes and imparts a spongy texture. Ghosh et al. (2020).

5.3. Bacillus spp:

These bacteria are widespread in Shidol, and they reduce down lipids and proteins to provide a soft texture and flavours that are rich in umami. Bacillus can additionally make antioxidants by using bioactive peptides (Ray et al., 2023).

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5.6. Mixed Microbial Communities:
The word refers to bacteria, yeasts, and moulds collaborating across multiple fermentation processes. In Gundruk, lactic acid bacteria (LAB) are essential during the earliest fermentation stages, while yeasts affect the final taste profile (Sha et al., 2013).

In West Bengal, making fermented foods involves a mix of cultural traditions and microbiology. All of the approaches are natural and basic, and they all rely on the good effects of bacteria that enhance the taste, shelf life, and nutrient content of food. This is the best arrangement of current food systems, but only if we know how those strategies work and what makes them work. This is a great chance to keep these vintage methods of doing things alive in the modern food chain.

6. Nutritional Composition and Health Benefits of Fermented Foods:

6.1. Macronutrients:
Fermented foods in West Bengal contain an array of macronutrients, such as proteins, carbs, and fats, that render them a crucial component of the region's diet. Proteins in fermented foods such as Shidol (fermented fish) and Chungdi (fermented milk) suffer partial hydrolysis during fermentation, yielding simpler peptides and amino acids that improve digestibility and absorption, thereby optimising nutrient usage by the human body (Ray et al., 2023). Carbohydrates in foods like panta bhat (fermented rice) and chal paneer (fermented rice pancakes) are broken down into simpler sugars, which renders them easier to digest and helps those with stomach problems (Tamang et al., 2020). Fermentation preserves and improves the fats in fermented foods like shidol. This makes less difficult for complicated lipids to break down into smaller units, like triglycerides and essential fatty acids (Roy et al., 2007). The macronutrients in fermented meals from the state improve health profiles and flavour and composition.

6.2. Micronutrients:
Proteins, carbs, and fats are important components of any meal, and the fermented foods of West Bengal are full of important micronutrients for the people that reside there. In Shidol and Chungdi, fermentation starts the process of breaking down complex proteins into smaller amino acid chains and peptides by enzymatic hydrolysis. This makes digestion easier and helps the body absorb nutrients (Ray et al., 2023). In meals like pantha bhat (fermented rice) and chal paneer (fermented rice pancakes), this process reduces some complex carbohydrates into simpler ones, making them easier for people with digestive problems to digest (Tamang et al., 2020). In addition, the creation of fermented foods like shidol preserves and enhances lipids, processing complicated lipids into more usable forms, such as triglycerides and essential fatty acids (Roy et al., 2007).

6.3. Bioactive Compounds:
Additionally, the changes that occur in macronutrients during fermentation not only make fermented foods more nutritious, but they also add to their unique flavour and texture. The process is crucial for making vitamins and minerals more available. Lactic acid bacteria, the microbes that cause fermentation, make water-soluble vitamins like B12 that are necessary for the neurological system to work properly and for the creation of blood cells (Manna, 2023). Lactic acid bacteria make panta bhat taste better and give it more B vitamins. Like the fermentation of gundruk by microbial synthesis of ascorbic acid. Fermenting leafy vegetables raises their vitamin C levels by a lot (Sha et al., 2013). Phytates and other antinutritional ingredients break down in raw meals, making minerals like calcium, iron, and zinc easier for the body to use. This is especially clear in pantha bhat, which lessens the amount of phytate and makes it easier for the body to absorb more iron (Hor et al., 2022). This process changes fermented foods into a useful source of important micronutrients, which makes them particularly effective for people who do not get enough nutrients.

Health Benefits:
6.4. Gut Health:
Fermented foods are full with beneficial microorganisms. Probiotics improve gut health by balancing the microbiota and making digestion easier. Pantha Bhat and Chundgi consume substantial amounts of LAB in their diet, enabling them to maintain an ideal gut pH, suppress pathogenic bacteria, and reduce acidity for the breakdown of short-chain fatty acids (Hor et al., 2022). It helps with digestion and eases stomach problems like constipation and irritable bowel syndrome (IBS). These fermented foods also have the right curative effects for conditions like relief. Tamang et al. (2020).

6.5. Immune Modulation:
Eating fermented foods on occasion boosts immunity by making you feel better. In chungdi and gundruk, the function of probiotics and lactic acid bacteria is essential for regulating the immune system. It additionally fosters the synthesis of cytokines and immunoglobulins, so fortifying the body's immune system (Sha et al., 2013). In addition, probiotics regulate inflammatory reactions, which lowers the risk of autoimmune illnesses and prolonged inflammation.

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6.6. Chronic Disease Prevention:
health by lowering triglyceride levels while lowering inflammation in the body (Ray et al., 2023). People with diabetes may find that eating fermented rice-based foods like chal paneer is good for them because they have a low glycaemic index, which helps keep blood sugar levels stable. Roy et al. (2007) contend that the antioxidants found in gundruk and other fermented vegetables counteract free radicals, thus lowering the incidence of oxidative stress-related diseases, including cancer and neurological problems.

These fermented foods from West Bengal are crucial as both traditional and functional foods, as shown by their health qualities and nutritional value. Fermentation adds bioactive molecules to our diet and raises the levels of macronutrients and micronutrients in basic foods, leading to them being more nutritious. These fermented foods also keep the body going and show how important they are in both old and new recipes. These are additional health benefits.It is important to maintain and safeguard the ancient fermentation methods of West Bengal in order to keep this culinary and nutritional heritage alive as more people learn about the health advantages of fermented foods.

7. Microbial Dynamics of Fermentation:

7.1. Essential microorganisms in fermentation:
Fermentation is an organic and complicated process that uses the metabolic activity of microbes to turn raw materials into food that tastes better, has more nutrients, and has a better texture. Panta bhat, shidol, and chungdi are distinctive traits of traditional fermented dishes from West Bengal, arising from the diverse microbial communities engaged in their manufacture. Lactic acid bacteria (LAB), yeasts, and Bacillus species each give food specific biochemical and sensory qualities. These are some of the most common types of microorganisms.

7.2. Lactic Acid Bacteria (LAB)
Bacteria that make lactic acid, predominantly from the Lactobacillus and Streptococcus species, are essential in fermented foods including panta bhat and chungdi. These bacteria break down carbs into disaccharides, including those in milk and rice. This makes lactic acid, which lowers pH and makes the environment acidic, which prevents spoilage and harmful microbes from growing (Hor et al., 2022). They not only help preserve food, but they also help the body make important nutrients, such as B-complex vitamins and organic acids that make the food they ferment healthier (Manna, 2023). The metabolic activity of LAB creates the mildly sour flavours that are common in LAB fermentation, which makes the dish more appealing.

7.3. Yeasts:
These microbes, that belong to the genus Saccharomyces, are frequently utilised to ferment starchy dishes like chal paneer (fermented rice pancakes). Yeasts make the batter rise and give it a light texture before baking. This is how chal panner pancakes acquire their fluffy, spongy texture: they turn sugars into carbon dioxide and ethanol, which makes the batter airy (Ghosh et al., 2020). Yeasts additionally produce esters and alcohols, which are fragrant molecules that make the food taste better overall. Their action breaks down complex polysaccharides, making the food easier to digest and more nutritious (Tamang et al., 2020).

Bacillus sp. are necessary for making proteolytic enzymes that break down fish proteins into peptides and free amino acids. These are found in fermented foods like shidol that are high in protein. This gives the dish a strong umami flavour (Ray et al., 2023). Bacillus enzymes help the body use necessary amino acids better, and thus render the food good for you. Bacillus sp. generates bioactive substances, such as antimicrobial peptides, that is help the fermented product last longer and make sure it is safe to eat (Roy et al., 2007).

8. Role of Microbes in Flavor, Texture, and Nutrient Enhancement:

The microorganisms involved in fermentation not only ensure the preservation of food but also significantly improve its nutritional and sensory properties.

8.1. Flavor Development:
Fermented foods have a unique flavour due to their include organic acids, esters, and alcohols, which are the metabolic by-products of fermentation. Lactic acid bacteria make lactic acid, giving chundgi and pantha bhat a tart and pleasant taste. In the same way, yeasts make volatile fragrance molecules during fermenting chal paneer, which gives it its unique smell (Ghosh et al., 2020). Bacillus sp. reduces down fish proteins in shidol, which releases free amino acids and peptides which add to its umami flavour (Ray et al., 2023).

8.2. Texture Enhancement:
The texture of fermented food is affected by microbial activity. Additionally. LAB deconstructs the intricate proteins and polysaccharides that contribute to the softening of food structures. In Pantha Bhat, the fermented rice attains a soft texture, facilitating easier mastication. According to Sha et al. (2013), yeasts cause the batter to rise and become airy prior to baking, resulting in fluffy, spongy chap pancakes. Bacillus species in shidol enzymatically decompose fish tissue, resulting in a paste-like

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consistency vital for its traditional application in chutneys and curries (Roy et al., 2007).

Table 1: Foods and their key nutritional constituents enhancing health benefits.

Food Item	Microorganisms	Key Nutritional Contributions	Health Benefits	References
Panta Bhat (Fermented Rice)	Lactic Acid Bacteria (LAB)	B-complex vitamins, Increased mineral bioavailability (Fe), Improved carbohydrate digestibility	Gut health, Immune modulation	Hor et al., 2022; Tamang et al., 2020; Manna, 2023
Gundruk (Fermented Leafy Greens)	LAB, Yeasts	Vitamin C, Increased phenolic compounds (antioxidants)	Immune modulation, Chronic disease prevention (antioxidant activity)	Sha et al., 2013; Roy et al., 2007
Chungdi (Fermented Milk)	LAB	Probiotics (Lactobacillus, Bifidobacterium), Improved protein digestibility	Gut health, Immune modulation	Tamang et al., 2022; Ray et al., 2023
Shidol (Fermented Fish)	Bacillus spp.	Omega-3 fatty acids, Bioactive peptides, Improved protein and fat digestibility	Chronic disease prevention (cardiovascular health), Umami flavor	Ray et al., 2023; Roy et al., 2007
Chal Paneer (Fermented Rice Pancakes)	Yeasts (Saccharomyces spp.)	Improved digestibility, Low glycemic index	Chronic disease prevention (diabetes management)	Ghosh et al., 2020; Tamang et al., 2020

8.3. Nutrient Enhancement:

Fermentation serves as a natural enhancement technique, augmenting the nutritional availability of components in raw ingredients. The nutritional content of fermented foods, particularly the generation of vitamins such as B12, is abundant in lactic acid bacteria (LAB), which are seldom present in plant-based diets (Manna, 2023). Furthermore, the acid generated by lactic acid bacteria and other fermentative microorganisms degrades antinutritional factors such as phytates, thereby enhancing the absorption of vital minerals (Hor et al., 2022). Yeasts play a pivotal role by enzymatically degrading complex monosaccharides and proteins, thereby enhancing the nutrient and caloric content of food (Tamang et al., 2020). The fermentation process of indigenous foods in West Bengal exemplifies the essential function of microbial agents in culinary innovation. LAB, yeasts, and Bacillus species enhance nutrient density, flavor, and texture. A profound understanding of this microbial synergy can enhance both health benefits and culinary heritage.

9. Comparison with Neighbouring Regions:

Fermented meals are a traditional staple in West Bengal and the states adjacent of Odisha, Sikkim, and Northeast India. Each of these areas has its own unique kind of fermented cuisine. Each of them has some things in common when it comes to how they are made and what they are made of. The fermented foods from each place differ because they use different types of microbes, different ways of making them, and different cultural settings.

In Odisha, they make fermented foods like pakhala bhata, which is a type of Bengal's panta bhat, by soaking cooked rice in cold water overnight. Curd, mustard seeds, and fried spices usually come with pakhal, which gives it a unique taste and smell. Some also have a side dish, such aloo posto. The addition of curd brings in Lactococcus species, which makes it more probiotic and makes it a more straightforward version of panta bhat from West Bengal (Das & Tamang, 2023). In Odisha, it is common to ferment pulses. For example, ambila is a sour lentil-based soup that absence of a direct analogue in West Bengal's cuisine.

People know Sikkim for its fermented delicacies, like gundruk and sinkhi, which are made by fermenting leafy greens. Nepali influence has also made gundruk popular in different regions of North Bengal. The preparation in Sikkim uses different drying and fermentation procedures that make the flavour better (Tamang et al., 2020). Sikkim is known for its fermented drinks, such as chang, an alcoholic drink made from millet. This shows that the region focusses on grain fermentation for brewing, which is not as common in West Bengal's cooking.

Assam, Meghalaya, and Manipur are states in Northeast India that have a long history of making fermented fish, soybeans, and bamboo shoots. As an instance, Manipur's ngari and Meghalaya's tungtap (fermented fish chutney) are like Bengal's shidol, but the way they are fermented is different. In Northeast India, fish frequently becomes fermented with little salt, depending on certain local bacteria. Shidol, on the other hand, is fermented without oxygen and with a lot of salt, which gives it a unique taste and texture (Ray et al., 2023). Additionally, Nagaland's axone (fermented soybean) isn't accessible in West Bengal, where soybeans are not a traditional ingredient.

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Table 2: Fermented Foods of different regions in India and their comparison.

Region	Fermented Food	Key Ingredients/ Features	Microbial Influence	Flavor Profile	Cultural Significance	Comparison to West Bengal	References
Odisha	Pakhala Bhata	Cooked rice, water, curd, mustard seeds, spices	Lactococcus spp. (from curd), other environmental microbes	Tangy, spiced	Common daily food	Similar to Panta Bhat but with added curd and spices	Das & Tamang, 2023
	Ambil	Lentils		Sour		No direct counterpart in West Bengal	Das & Tamang, 2023
Sikkim	Gundruk	Leafy greens		Robust, earthy		Similar to North Bengal's Gundruk but with different drying/fermentation techniques	Tamang et al., 2020
	Sinkhi	Leafy greens				Similar to Gundruk	Tamang et al., 2020
	Chang	Millet		Alcoholic		Grain fermentation less prominent in West Bengal	Tamang et al., 2020
Northeast India (e.g., Manipur, Meghalaya, Nagaland)	Ngari (Manipur), Tungtap (Meghalaya)	Fish	Local microbes, minimal salt			Similar to Shidol but with different fermentation processes (less salt)	Ray et al., 2023
	Axone (Nagaland)	Soybean				No direct counterpart in West Bengal (soybean not a traditional ingredient)	Ray et al., 2023
West Bengal	Panta Bhat	Cooked rice, water	Lactobacillus, Pediococcus, environmental microbes	Mildly tangy	Pohela Boishakh celebration	Simpler preparation, relies on natural microbes	Hor et al., 2022; Tamang et al., 1988
	Shidol	Fish	Anaerobic fermentation, significant salting	Strong, pungent	Common condiment, tribal cuisines	Different fermentation process (more salt) compared to Northeast Indian fermented fish	Ray et al., 2023; Tamang et al., 1988
	Chungdi	Milk				Dairy-based fermentation less common in neighboring regions	Tamang et al., 1988
	Gundruk	Leafy Greens				Similar to Sikkim's Gundruk, but possibly different preparation	Tamang et al., 2020

9.1. Unique Aspects of Fermentation Practices in West Bengal:

The fermentation of West Bengal has significance because it is easy to do and because there are bacteria that naturally present in the area. It might not need much work, yet it lets regional microbial communities thrive. You only need water and cooked rice to make panta bhat. Completely dependent on ambient microorganisms like Lactobacillus and Pediococcus to start fermentation (Hor et al., 2022). In Northeast India, on the opposite hand, hamei or bekang, a pre-prepared culture, is added to the fermenting process to help it along.

Another fascinating fact is that there are many different types of fermented foods that can be eaten with any meal. Shidol is a protein-rich sauce, panta bhat is a common food, and chungdi is a dairy-based alternative. The balance of rice, fish, and milk fermentation in Bengal is an excellent demonstration of how the people there live off the land (Tamang et al., 1988). Also, the state's fermented meals have more mild aromas, and they don't rely as much on strong spices or strong ingredients. This makes them quicker for a wider range of tastes to get to.

The cultural importance further distinguishes the fermented foods of Bengal. Dishes like panta bhat are associated with festivals such as 'Pohela Boishakh', while shidol is emblematic of tribal cuisines in Northern Bengal; these dishes maintain the culinary identity of these communities. In contrast, fermented foods in Sikkim and Northeast India are primarily consumed for their preservative qualities and robust flavors, with minimal or no direct association with festivals or rituals.

10. Challenges and Future Perspectives:

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10.1. Preservation of Traditional Fermentation Techniques:

The absence of structured recording and changing lifestyle patterns are progressively impeding the preservation of West Bengal's cultural fermenting expertise, preventing the transmission of these habits. (Tamang et al., 2020). Using earthen pots for panta bhat fermentation and making shidol in bamboo are examples of traditional knowledge and environmental factors that are being replaced by contemporary methods. This change typically changes the taste and makes the different types of microbes in these foods less common. These techniques can be kept alive and cultural arts can be kept going with the help of traditional craftspeople, outreach to the public, and training sessions.

10.2. Threats Due to Modernization and Urbanization:

The indigenous fermentation tradition in West Bengal is under serious threat from modernisation and urbanisation. The rise of processed and packaged foods has made people eat fewer fermented foods that they make themselves. People choose convenience foods more and more. Ray et al. (2023). In cities, people don't have enough access to the best environmental conditions and natural resources. It makes it more difficult to make traditional fermented dishes like shidol and gundruk. Also, if younger people move to cities, they lose touch with their cultural heritage, which leads to the loss of indigenous knowledge. This undermined the health benefits which come with eating fermented vegetables the old-fashioned way. Mass-produced foods may don't have the same amount of nutrients and probiotics.

10.3. Potential for Commercialization and Scaling:

There are still problems, but there is a lot of room for the marketing and growth of fermented foods from West Bengal that have already been produced. Panta bhat, shidol, and chungdi can be marketed as probiotic-rich and useful products for health-conscious consumers both locally and internationally. The packaging of these items, which adheres to modern food safety rules, keeps their traditional flavour while making it easier to enter new markets (Tamang et al., 2022). Furthermore, the economic benefits of commercialisation must ensure the participation of local communities and small-scale farmers for equitable sustainability. To improve these foods, research will be necessary to find ways to make them last longer, make sure they are made the same way every time, and keep microbes alive without ruining their history and nutritional value.

10.4. Opportunities for Scientific Research and Development in Functional Foods:

Fermented foods from West Bengal are captivating since they contain a lot of different types of microbes and health advantages. This creates opportunities for the creation and scientific study of foods that are better for you.

'Panta bhat' or 'chungdi' leads to research on isolated probiotic strains, which leads to the use of beneficial microbes in nutraceuticals and supplements (Hor et al., 2022). Studies on bioactive compounds such as 'gundruk' and 'shidol' show positive effects on illness management and prevention. Like diabetes and cardiovascular disease. Food scientists, microbiologists, and traditional knowledge guardians collaborating to can combine modern science with old cooking methods to create functional foods that are good for health for individuals around the world while also being true to their cultural roots.

CONCLUSION:

The fermented foods of West Bengal have been very important since they are both important parts of the region's historical culture and nutritional offerings. Fermented foods like Panta Bhat, Shidol, and Chungdi show how traditional food systems can be rich in assets that make nutrients more available, provide good probiotics, and improve health in general (Roy et al., 2007). These foods connect people to their roots and help them feel like they belong. Still, urbanisation, modernisation, and not enough efforts for preserving these fermented foods put their continued existence at risk.

To protect these traditional foods, it will be essential to keep track of fermentation methods, get people involved, and let people know about the health benefits of these foods. Research and development could identify their potential benefits as functional foods, providing modern customers with healthier dietary options while advocating traditional knowledge (Tamang et al., 2020). The ethical and inclusive distribution of these goods can help local businesses and protect the rich culture of West Bengal. Further investigation should focus on the characterisation of microorganisms, the health effects of fermented foods, and the advancement of sustainable production methods to ensure the ongoing relevance and availability of these foods in contemporary life. These fermented foods from West Bengal can last by combining traditional expertise with contemporary technology. This will improve both local and global cooking.

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