**A Review on Diversity and Applications of Traditional and Modern Millet and Cereal- based Probiotic Beverages**

**Abstract**

**Background:** Probiotic beverages based on cereal and millet are popular due to their numerous health benefits and as non dairy alternative-suitability for lactose intolerant people. These beverages have probiotic strains like *Lactobacillus* and *Streptococcus.* Probiotic formulations may help prevent and manage cardiovascular disease, type 2 diabetes, and obesity by enhancing antioxidant activity and reducing inflammation through improved bioavailability of phenolics and flavonoids. The study brigdes the gap between traditional knowledge and modern in sight of probiotics drinks. It offers the insight on diversity of probiotics drinks and can guide researchers in developing sustainable plant based drinks.

**Methods:** Several studies on cereal and millet based traditional and recent probiotic drink were extensively reviewed from different databases, including PubMed, Scopus, and Google Scholar. The key terms included were *"cereal-based probiotic drinks,"* *"millet-based probiotic beverages,"* and *"fermentation techniques for probiotic beverages."* for fermentation process, storage stability and viability of probiotic bacteria and sensory attributes. The review investigates various fermentation methods, formulation, the impact of different probiotic strains, and their effects on the nutritional and functional properties of these beverages.

**Results**: Fermentation improved the nutritional profile of cereal and millet based beverages, increasing antioxidants, fiber, and protein content. Probiotic viability was maintained at high CFU levels (10⁶–10¹² CFU/ml) for 4–5 weeks under refrigeration. Sensory evaluations indicated high consumer acceptability, especially for fruit-flavoured variants.

**Conclusions:** Cereal and millet-based probiotic drinks are promising functional beverages with significant health benefits and commercial potential. Future research should focus on optimizing fermentation techniques, extending shelf life, and diversifying product formulations to enhance consumer acceptance and scalability.

**Keywords**

 Cereal-based beverages, millet-based drinks, probiotics, functional foods, non-dairy alternatives.

### ****I. Introduction****

Cereal- and millet-based probiotic beverages are emerging as sustainable, non-dairy alternatives that align with health-conscious and climate-resilient food systems. Derived from cereals such as wheat, rice, and barley, and nutrient-rich millets like finger millet, proso millet, and foxtail millet, these beverages provide essential nutrients including dietary fiber, B-vitamins, and minerals. Millets, often termed “nutri-cereals,” are particularly valuable in regions with nutrient-poor soils and adverse climatic conditions (Kothapalli *et al*., 2024).

Fermentation with probiotics significantly enhances the nutritional and functional properties of these grains. According to the FAO/WHO (2001), probiotics are defined as live microorganisms which, when administered in adequate amounts, confer a health benefit on the host. Fermentation improves the digestibility of cereals and millets, supports the gut microbiota, and boosts immune function (Agrawal *et al*., 2005). These microorganisms—mainly species of Lactobacillusand Bifidobacterium—have demonstrated therapeutic potential across a range of health outcomes, including mitigation of rotavirus diarrhea (Wang *et al*., 2014), relief from lactose intolerance (Kechagia *et al*., 2013), improved lipid profiles (Marras *et al*., 2021), enhanced micronutrient absorption (Hemalatha *et al*., 2017), and reduced susceptibility to infections and allergic responses (Gallego *et al*., 2016).

In the context of food-based probiotic delivery systems, both cereals and millets serve as valuable substrates due to their naturally high content of carbohydrates, proteins, vitamins, and minerals that support the growth and metabolic activity of probiotic microorganisms during fermentation (Das *et al*., 2020). However, a comparative analysis reveals that millets offer distinct advantages over conventional cereals (Luana *et al*., 2017). Millets such as finger and pearl millet possess significantly higher levels of dietary fiber and essential minerals like calcium, iron, and magnesium, which not only enhance the nutritional profile of the final product but also support more efficient microbial fermentation (Luana *et al*., 2017). In contrast, conventional cereals such as rice and wheat, while adequate in terms of carbohydrate and protein content, generally have lower fiber and mineral concentrations (Das *et al*., 2020). This makes millets especially valuable in the development of functional probiotic beverages, particularly in non-dairy and gluten-free applications where nutritional enhancement and fermentation compatibility are critical (Luana *et al*., 2017).

Beyond nutritional enhancement, probiotic fermentation of these beverages increases the production of short-chain fatty acids (SCFAs), compounds known to reinforce gut barrier function and support intestinal health (Jäger *et al*., 2020). It also stimulates immune responses by enhancing the activity of natural killer (NK) cells and immunoglobulin production (Gallego *et al*., 2016). Moreover, the inherent dietary fiber in cereals and millets acts as a prebiotic, selectively encouraging the proliferation of beneficial gut bacteria.

Fermentation enhances antioxidant capacity and increases the bioavailability of phenolic compounds and flavonoids, which play roles in modulating oxidative stress and inflammation (Luana *et al*., 2017). A randomized controlled trial showed that consumption of a fermented probiotic drink significantly reduced serum cholesterol, blood pressure, and inflammatory markers in individuals with metabolic syndrome (Ejtahed *et al*., 2011).

Dairy *Propionibacterium*, known for producing vitamin B12, can be effectively used in in situ fermentation to develop vegan-friendly foods. In a study, 138 cultures were isolated from raw cow’s milk, Swiss cheese, and curd to identify the genotypic traits of *Propionibacterium* spp. Among them, strain MM21 emerged as a high B12 producer. Millet-based beverages fermented with MM21 demonstrated its potential as a suitable starter culture for enriching foods with vitamin B12 (Punniyamoorthy *et al*., 2025). Nandhini *et al.* (2025) isolated LAB strains from South Indian fermented cereals and identified through biochemical, molecular, and physiological assays. Morphological analysis showed varied colony shapes and colors, with gram-positive rods and cocci present. High antioxidant activity (>80% in DPPH assay) and positive carbohydrate fermentation confirmed probiotic potential. 16S rRNA analysis identified *Lactobacillus plantarum* and *Lactococcus lactis* in pearl, finger, and foxtail millets. These strains enhance gut health, nutrient absorption, and overall functional value of fermented millets.

Barnyard millet, valued for its drought resistance, high energy yield, and rich content of fiber, protein, iron, and zinc, offers significant nutritional benefits. Joseph *et al*. (2025) developed eight health drink formulations using barnyard millet and *Spirulina sp.*, fermented with *Lactobacillus rhamnosus* and *Saccharomyces cerevisiae* (unflavoured and flavoured). Protein content ranged from 1.39–4.61% in *L. rhamnosus* samples and 2.52–4.09% in *S. cerevisiae* samples. Carbohydrate content (5–14.8%) was suitable for diabetic consumption. Sensory evaluation revealed that LRFFD (Lactobacillus rhamnosus fermented flavoured drink) and SCFFD **(**Saccharomyces cerevisiae fermented flavoured drink) had the most favorable taste, attributed to the inclusion of flavouring agents. GC–MS analysis detected bioactive compounds such as oleic acid, known for lowering cholesterol and reducing inflammation, and hexadecenoic acid, associated with Alzheimer's disease management. The presence of probiotics in all formulations supports gastrointestinal health. (Joseph *et al*., 2025).

Additionally, the high fiber content of millets promotes satiety and supports a balanced gut microbiota, aiding in weight management and metabolic regulation (Rao *et al*., 2020). Consumer acceptance studies have also shown that millet-based probiotic beverages tailored for elderly individuals have been well-received, demonstrating their viability in functional food markets (Bembem & Agrahar-Murugkar, 2020). This review thus highlights the traditional and new probiotic cereal and millet based beverages. Its growing relevance of cereal- and millet-based probiotic drinks as functional, nutrient-dense, and health-promoting food products.

### ****II. Methodology****

The current review provides a detailed analysis of cereal and millet based drinks, fermentation techniques, types of probiotics used, probiotic viability, bioactive compound enhancement, , traditional probiotic drinks, effectiveness, cultures used and sensory evaluations and shelf-life stability. Studies that provided quantitative data on microbial counts (CFU/ml), storage conditions, and their impact on beverage quality. Data were synthesized to compare different probiotic strains, such as *Lactobacillus*, *Bifidobacterium*, and *Pediococcus*, along with the effects of fermentation on the nutritional composition, antioxidant levels, and overall health benefits of the beverages. This study was conducted by extensively searching different databases, including PubMed, Scopus, and Google Scholar. The key terms included were *"cereal-based probiotic drinks,"* *"millet-based probiotic beverages,"* and *"fermentation techniques for probiotic beverages."* The inclusion criteria focused on studies that investigated probiotic strains, fermentation processes, sensory characteristics, and storage stability of these beverages. Experimental and review studies that have been published in the last two decades are includedin the current review.

**III. Results**

Probiotics are live microorganisms that, when consumed in sufficient quantities, provide beneficial effects on human health (FAO/WHO, 2001). **As an integral component of functional foods, they contribute significantly to maintaining gut health by promoting the growth of beneficial microbes (Hill *et al.,* 2014).** Predominantly from the *Lactobacillus* and *Bifidobacterium*genera, these microorganisms can function individually or synergistically to support various physiological processes (Ouwehand *et al.,* 2002). Studies have highlighted a wide array of health-promoting effects associated with probiotics, including reduced duration of rotavirus-induced diarrhea, improved lactose digestion, lowered blood cholesterol levels, enhanced micronutrient uptake, and decreased incidence of allergies and infections (Gallego et al., 2016).For instance, Lactobacillus rhamnosus GG has been shown to reduce the duration of rotavirus-induced diarrhea by approximately 18–25 hours in infected children (Szajewska & Mrukowicz, 2001). Probiotic strains like Lactobacillus acidophilus enhance lactose digestion by producing β-galactosidase, aiding in the breakdown of lactose in the gut (de Vrese *et al.,* 2001). Clinical trials demonstrate that probiotic-rich fermented milk significantly lowers total and LDL cholesterol by 5–8%, mainly through bile salt deconjugation and cholesterol assimilation (Jones et al., 2012). Moreover, strains such as L.rhamnosus and Bifidobacterium spp. improve micronutrient uptake, particularly B vitamins (LeBlanc *et al.,* 2013). Probiotics also decrease allergy incidence and infections by enhancing mucosal immunity and reducing pathogen colonization (Fiocchi *et al.*, 2015).

These effects are mediated through several mechanisms such as the production of antimicrobial substances, modulation of immune responses, and competition with pathogens for binding sites and nutrients. Importantly, these benefits are often specific to the probiotic strain used, emphasizing the necessity of selecting appropriate strains tailored to particular health conditions (Kechagia et al., 2013).

The grain matrix of cereals and millets serves as an excellent substrate for probiotic growth due to their natural abundance of complex carbohydrates, proteins, and micronutrients. These grains are also rich in B-complex vitamins—such as thiamine, riboflavin, niacin, and folate—which play critical roles in metabolism, neurological health, and DNA synthesis (Devi *et al*., 2014). Additionally, the presence of iron, calcium, magnesium, phosphorus, and manganese supports hematological, skeletal, muscular, and enzymatic functions (Srivastava *et al*., 2021).

Successful fermentation of cereal- and millet-based beverages requires careful regulation of several parameters—namely temperature, pH, inoculum concentration, and fermentation time. These factors influence microbial metabolism and ultimately determine the quality and stability of the final product. For instance, optimal fermentation conditions encourage controlled lactic acid production, which not only imparts a desirable tangy flavor but also enhances the product's shelf life and microbial safety (Jäger et al., 2020). A diverse range of probiotic organisms has been identified for human use. Among the Lactobacillus species, notable examples include L. plantarum, L. fermentum, L. brevis, L. acidophilus, L. rhamnosus, L. gasseri, L. bulgaricus, and L. crispatus (Ivonne et al., 2011). The Bifidobacterium group encompasses species such as B. infantis, B. lactis, B. breve, B. animalis, and B. adolescentis. Other genera with recognized probiotic strains include Propionibacterium, Lactococcus lactis, and the yeast Saccharomyces boulardii.

Macronutrient composition and micronutrient profiles of these grains, which play a critical role in supporting fermentation and contributing to health outcomes, are detailed in Table 1 and Table 2.

**Traditional Cereal and Millet-Based Probiotic Drinks World-wide**

Traditional fermented beverages are an integral part of many cultures across the globe, offering not only nutritional benefits but also deep-rooted social and cultural significance. These drinks vary in their base ingredients, microbial compositions, and methods of preparation, often reflecting the local agricultural resources and culinary traditions of their regions. A few notable examples include: **Ogi (Nigeria)** (Molin *et al*., 2003),**Togwa (Tanzania)**(Lorri & Svanberg, 1995), **ProViva (Sweden)** –(Molin *et al*., 2003), **Boza (Turkey)** (Arici & Daglioglu, 2002), **Pito (West Africa)** (Kolawole *et al*., 2007) **Obiolo (Nigeria)** (Ukwuru & Ohaegbu, 2018), **Burukutu (Nigeria, Benin, Ghana)** (Ekundayo *et al*., 1969), **Kunu-Zaki (Nigeria)** (Adeyemi & Umar, 1994), **Kishk (Middle East, Europe)** (Abd-el-Malek & Demerdash, 1993), **Tarhana (Greece, Turkey)**(Campbell-Platt *et al*., 1994),**Sake (Japan, China)** (Lotong *et al*., 1998), **Chicha (South America)**  (Escobar *et al*., 1993), **Mahewu (Africa, Arabian Gulf)** (Odunfa *et al*., 2001), **Bouza (Egypt, Turkey, Eastern Europe)** (Morcos *et al*., 1973), **Mangisi (Africa)** ( Zvauya *et al*., 1997) and **Bushera (Uganda)**(Muyanja *et al*., 2003). Comparative analysis of Cereal- and millet-based Traditional drinks is given in Table-3.

Ogi (Nigeria) is a soft, fermented porridge made from maize, millet, or sorghum, commonly used as a weaning food. It has a smooth texture and tangy taste, but a short shelf life unless refrigerated. It is culturally important in Nigerian households and is usually prepared fresh. (Molin *et al*., 2003). Ogi is traditionally prepared by soaking maize, millet, or sorghum in water for 1–3 days to allow for natural fermentation. The soaked grains are then wet-milled into a slurry, sieved to remove bran, and left to ferment further for another day or two. The fermentation is spontaneous, involving naturally occurring lactic acid bacteria, particularly Lactobacillus plantarum, which acidifies the slurry, leading to a smooth, sour porridge-like product (Molin *et al*., 2003). The fermentation process improves protein digestibility, reduces phytic acid content (an antinutrient), and enhances mineral bioavailability. Ogi is commonly used as a weaning food for infants due to its soft texture, improved nutritional profile, and microbial safety (Molin *et al*., 2003).

Togwa (Tanzania) is a porridge-like beverage made from cereals or cassava, naturally fermented with lactic acid bacteria and yeasts. Togwa is made from cereals like maize or sorghum, or cassava. The grains are ground and mixed with water to form a thick porridge. The mixture is left to undergo natural fermentation for 24 to 48 hours, primarily driven by lactic acid bacteria and yeasts. The fermentation process is often spontaneous and conducted at ambient temperatures. Togwa has a moderate shelf life and is often consumed as a functional beverage. Togwa is valued for its contribution to child nutrition, particularly in rural Tanzanian communities. The fermentation reduces pathogenic bacteria, increases B vitamin content, and produces organic acids that improve digestibility and support gut health (Lorri & Svanberg, 1995).

ProViva (Sweden) is a commercially produced oat-based probiotic drink containing *L. plantarum 299v*. It is fermented using a specific strain, Lactobacillus plantarum 299v, under controlled conditions. The fermentation is followed by pasteurization and the addition of fruit juice for flavoring. The production ensures consistency, extended shelf life, and the retention of viable probiotic cells (Molin *et al*., 2003).It is often flavored with fruit juices and is marketed for digestive wellness. With a long shelf life due to industrial processing, ProViva stands out as a modern, gut-friendly product using oats—a non-traditional fermentation base. (Molin *et al*., 2003). ProViva is marketed for its digestive health benefits. Regular consumption has been shown to improve bowel regularity and enhance gut microbiota composition. The oat base also contributes dietary fiber, particularly β-glucans, which may help reduce cholesterol levels (Molin *et al*., 2003).

Boza (Turkey) is a thick, sweet-sour drink made from millet, maize, or wheat, fermented by lactic acid bacteria and yeasts. It is slightly alcoholic and nutrient-rich, traditionally consumed in the winter for its warming properties. Boza reflects regional variations and has deep cultural roots in Turkey and neighboring regions. Boza is prepared by boiling ground cereals such as millet, maize, or wheat into a thick mash, which is then cooled and inoculated with a previous batch (back-slopping) or left to ferment spontaneously for one to three days. The fermentation involves both lactic acid bacteria and yeasts, resulting in a slightly alcoholic, thick, sweet-sour beverage. Boza is nutrient-rich, providing carbohydrates, B vitamins, and probiotics. The drink offers antimicrobial properties due to organic acid production, supports digestive health, and helps maintain a balanced intestinal flora (Arici & Daglioglu, 2002).

Pito is made by malting and fermenting sorghum or millet. The grains are soaked, germinated, dried, and milled. The malted flour is mixed with water, boiled into a mash, and left to ferment for 24–48 hours. The resulting beverage is slightly alcoholic and traditionally consumed fresh. Pito contains probiotic bacteria and yeasts that produce lactic acid and ethanol, contributing to gut health and microbial balance. However, due to its alcohol content, it is not recommended for children or pregnant women (Kolawole *et al*., 2007).

Obiolo is prepared by fermenting millet or sorghum flour mixed with water. The mixture is boiled, cooled, and left to ferment naturally for 12–24 hours. The fermentation enhances microbial growth, mainly lactic acid bacteria, and may be consumed with added sweeteners. Obiolo improves gut microbiota and is considered beneficial for children and individuals with digestive issues. It also offers a source of B vitamins and minerals, aiding in nutrient absorption and immune function (Ukwuru & Ohaegbu, 2018).

Burukutu (Nigeria, Benin, Ghana) is an alcoholic beverage made from guinea corn, known for its sour, vinegar-like taste and probiotic richness. Burukutu is a traditional alcoholic beverage made by fermenting guinea corn. The grains are malted, mashed, and boiled, followed by fermentation for 1–2 days. The process includes spontaneous fermentation using environmental microbes, resulting in a sour, slightly alcoholic drink . Despite being alcoholic, Burukutu is rich in organic acids and microbial metabolites that support digestion and inhibit harmful bacteria. It is culturally significant and consumed during ceremonies, though not suitable for children (Ekundayo *et al*., 1969).

Kunu-Zaki (Nigeria) is made by soaking millet for 24 hours, wet-milling it with spices like ginger and clove, and boiling part of the slurry. The hot portion is mixed back with the raw slurry and left to ferment for 12–24 hours before sweetening and consumption. This non-alcoholic drink is hydrating and rich in micronutrients. It serves as both a weaning food and an energy drink, particularly in hot climates. The lactic acid fermentation aids in digestion and improves the safety of the beverage (Adeyemi & Umar, 1994).

Kishk (Middle East, Europe) is a dried fermented blend of wheat and yogurt, rich in B vitamins and minerals.It is prepared by fermenting a mixture of yogurt and parboiled cracked wheat (bulgur). The blend is fermented for 2–3 days and then sun-dried and ground into powder. This shelf-stable product can be stored for long periods and is rehydrated for soups or porridge. It is shelf-stable and can be stored for long periods, making it ideal for regions with harsh climates. Kishk is often rehydrated into soups and porridges and serves as a nutritional supplement. Kishk is rich in B vitamins, protein, and minerals. It provides probiotic benefits even in dried form and supports immune and gut health in regions with limited access to refrigeration (Abd-el-Malek & Demerdash, 1993).

Tarhana (Greece, Turkey) is a dried mixture of fermented wheat, yogurt, and vegetables, typically rehydrated and used in soups. Tarhana is made by fermenting a mix of wheat flour, yogurt, vegetables (like onions and tomatoes), and spices. The mixture is fermented for 1–2 days, dried under the sun, and crumbled into granules for long-term storage. Its drying process extends shelf life significantly, combining fermentation with preservation. The fermentation increases bioavailability of nutrients and introduces beneficial lactic acid bacteria. Tarhana is used in soups and offers a stable source of nutrition and mild probiotics (Campbell-Platt *et al*., 1994).

Sake (Japan, China is a rice wine produced through multiple parallel fermentations. Steamed rice is inoculated with Aspergillus oryzae (koji mold) to convert starches into sugars. Yeasts and lactic acid bacteria are then added to ferment sugars into alcohol under controlled conditions (Lotong *et al*., 1998). While alcoholic, sake contains bioactive peptides and antioxidants that may support cardiovascular and digestive health. It also holds ceremonial and cultural importance (Lotong *et al*., 1998).

Chicha (South America) is prepared by fermenting maize. In some traditional methods, maize is chewed to release enzymes that break down starches, then spit into a container to ferment. Alternatively, it is boiled, cooled, and naturally fermented using environmental. Chicha provides lactic acid bacteria, B vitamins, and organic acids. It supports hydration, digestion, and social bonding in indigenous communities (Escobar *et al*., 1993).

Mahewu (Africa, Arabian Gulf)is made by cooking maize meal into a thick porridge, cooling it, and inoculating with malted sorghum or millet. The mix is left to ferment for 12–24 hours to yield a sour, non-alcoholic beverage. Mahewu is commonly consumed as a weaning and energy drink. It is probiotic-rich and improves gut flora, especially beneficial in hot climates for hydration and nutrition (Odunfa *et al*., 2001).

Bouza (Egypt, Turkey, Eastern Europe) is produced from fermented malted wheat. The grain is soaked, germinated, dried, milled, and then boiled into a thick mash. The mixture is left to ferment naturally, often for 2–3 days, resulting in a mildly alcoholic drink. Bouza offers B vitamins, organic acids, and probiotics. Though alcoholic, it has digestive benefits and has been consumed historically for both nutrition and refreshment (Morcos *et al*., 1973).

Mangisi (Africa)is a traditional fermented drink made from finger millet. The grains are soaked, malted, dried, and ground into flour, then mixed with water and left to ferment. The resulting drink is slightly alcoholic and consumed fresh. Mangisi is rich in probiotics, iron, and fiber. It supports digestion and is often used in ceremonies and as a functional drink in rural areas (Zvauya *et al*., 1997).

Bushera (Uganda) is made by mixing millet or sorghum flour with water, cooking the mixture, and allowing it to cool. It is then fermented naturally over 1–3 days using environmental lactic acid bacteria and yeasts. Bushera is a probiotic-rich drink that improves gut health and provides essential nutrients such as B vitamins and iron. It is commonly given to children and valued for both its taste and nutritional benefits (Muyanja *et al*., 2003).

**Traditional Cereal and Millet-Based Probiotic Drinks from India**

 India, with its rich cultural diversity and deep-rooted traditions, is home to a wide variety of indigenous fermented beverages. These drinks are region-specific, often prepared using local grains and traditional starter cultures, and play important roles in community life and nutrition. Notable examples of cereal fermented drinks from India include: Rabadi (Pintu & Verma, 2019), Haria (Ghosh et al., 2014), Apong (Das et al., 2012), Judima (Chakrabarty et al., 2014), Zutho(Das et al., 2012), Rice Jann (Roy et al., 2004), Kodo ka Jaanr (Thapa & Tamang, 2004), Sur/Sura (Navdeep et al., 2015), Shhang/Ccharo-Kham (Shrivastava et al., 2012), Bhaati Jaanr (Tamang & Thapa, 2006), Raksi (Kozaki et al., 2000), Tchang/Jhar (Sekar & Mariappan, 2007), Rokshi (Sekar & Mariappan, 2007), and Yu (Singh & Singh, 2006).

**Rabadi (Northwestern India – Rajasthan, Haryana, Punjab)** is a traditional fermented drink prepared by mixing barley or pearl millet flour with sour buttermilk to form a slurry, which is sun-fermented for 6–8 hours. After fermentation, the mixture is gently boiled, cooled, and seasoned with spices like cumin or ajwain before serving. It is typically consumed fresh due to its short shelf life. The fermentation process enhances protein digestibility, reduces phytates, and increases the bioavailability of minerals and B-vitamins. Rich in probiotics, Rabadi supports gut health, aids digestion, and provides hydration, especially in hot climates (Pintu & Verma, 2019).

**Haria (West Bengal & East-Central India** is a traditional rice-based fermented drink prepared by boiling rice, cooling it, and inoculating it with **bakhar**, a locally made herbal starter culture. The mixture is transferred to **earthen pots** and left to ferment naturally at room temperature for 3–5 days. The fermentation is driven by indigenous **yeasts (e.g.,** Saccharomyces spp.**)** and **lactic acid bacteria**(Ghosh et al., 2014).
Haria is rich in **probiotics**, **organic acids**, and **antioxidants**, which promote digestive health, boost immunity, and act as a **natural cooling agent**. Among tribal communities, it is also used to manage **fatigue**, **digestive disorders**, and **nutrient deficiencies**, serving both as a food and functional remedy (Ghosh et al., 2014).

**Apong (Arunachal Pradesh)** is a traditional fermented beverage made by cooking glutinous rice, mixing it with ash obtained from burnt paddy husk and straw, and inoculating it with a traditional starter culture known as epop. The mixture is then left to ferment in bamboo baskets or earthen pots for approximately 20 days under ambient conditions. Apong contains beneficial microorganisms, antioxidants, and bioactive compounds that contribute to its antimicrobial, antioxidant, and anti-aging properties. It is also traditionally believed to aid in preventing kidney stones and promoting gut and metabolic health, making it a valuable functional food (Das *et al*., 2012).

**Judima (Assam)** is a traditional rice-based fermented drink made by cooking sticky or glutinous rice, which is then cooled and mixed with a powdered starter culture known as humao. This starter, prepared from local herbs and rice flour, contains naturally occurring yeasts and molds. The inoculated rice is placed in bamboo baskets or earthen pots and left to ferment for several days under ambient conditions. The fermentation process yields a mildly sweet, fragrant, and slightly alcoholic liquid that is typically strained and consumed fresh. Judima contains beneficial microorganisms such as Saccharomyces cerevisiae and a range of digestive enzymes. These contribute to improved digestion, enhanced nutrient bioavailability, and gut health. Traditionally, it is consumed by the Dimasa tribe to support postpartum recovery, aid in digestion among the elderly, and provide energy and metabolic support during rituals and community events (Chakrabarty *et al*., 2014).

**Zutho (Nagaland)** is a traditional fermented rice beverage widely consumed in Nagaland. It is prepared by cooking rice, cooling it, and then mixing it with a locally made grist starter culture composed of dried rice and naturally occurring microorganisms. The mixture is left to ferment in earthen pots or bamboo containers for 2 to 3 days at room temperature. This short fermentation process yields a mildly alcoholic, aromatic liquid with a slightly sour taste. Zutho is traditionally valued for its therapeutic properties. It is believed to help regulate insulin levels, improve appetite, accelerate wound healing, and enhance immunity. These benefits are attributed to the presence of probiotic microorganisms, bioactive compounds, and enzymes produced during fermentation (Das *et al.,* 2012).

**Rice Jann (Himalayan regions**)is a traditional fermented beverage made from cooked rice, inoculated with a local starter culture called balam. The rice is steamed, cooled, and mixed with the powdered starter, then packed into bamboo baskets or earthenware and covered with leaves or cloth. It is left to ferment for an extended period of 6 to 10 months in cool, shaded conditions typical of the Himalayan climate. Rice Jann is consumed primarily for its warming and nourishing properties, especially during harsh winters. It provides calories, mild alcohol for thermogenesis, and fermentation-derived bioactive compounds that support digestion, immunity, and general vitality in cold environments (Roy *et al*., 2004).

**Kodo ka Jaanr (Himalayan regions)** is prepared using finger millet (kodo millet). The grains are soaked, steamed, and inoculated with marcha or other regional starter cultures. The mixture is allowed to ferment in bamboo baskets or containers for several days. The resulting mildly alcoholic beverage is strained before consumption. This drink is highly nutritious, rich in iron, calcium, and B vitamins. It is traditionally used as a **restorative tonic** for postpartum women, the elderly, and those recovering from illness. Its probiotic content aids digestion and improves micronutrient absorption, making it valuable for nutritional rehabilitation (Thapa & Tamang, 2004).

**Sur or Sura (Himachal Pradesh & Uttarakhand)** is a traditional alcoholic beverage made from finger millet. The millet is washed, soaked, steamed, and cooled before being mixed with a local starter culture. The mixture is packed into bamboo or earthen containers and fermented naturally for several days. The strained liquid is consumed fresh or slightly aged, often during cultural festivals or as a post-labor restorative. Sur is rich in B-complex vitamins, essential amino acids, antioxidants, and fermentation-derived probiotics. It is traditionally believed to aid digestion, provide warmth, and promote energy recovery, especially in cold mountain regions and during physical fatigue (Navdeep *et al*., 2015).

 **Shhang or Ccharo-Kham (Arunachal Pradesh)** is a barley-based fermented drink prepared by steaming barley grains, cooling them, and mixing them with a traditional starter culture composed of native herbs and wild yeasts. The mixture is allowed to ferment in bamboo or earthen containers under natural conditions. The fermentation period varies but typically lasts several days . This drink reflects the Karbi tribe’s fermentation heritage and offers mild alcoholic content, along with antioxidants and probiotic organisms that support digestion, immunity, and metabolic balance. It is also consumed during religious and social ceremonies (Shrivastava *et al*., 2012).

**Bhaati Jaanr (Sikkim, Darjeeling)** is made from cooked rice that is cooled and mixed with marcha (a traditional starter containing wild yeasts and molds). The mixture is packed in bamboo baskets lined with leaves and fermented at room temperature for several days. The resulting sweet-sour, mildly alcoholic drink is typically consumed unfiltered. Bhaati Jaanr is rich in probiotics, calcium, iron, potassium, and B vitamins. It is traditionally consumed for its digestive and nutritional benefits, especially for postpartum women, the elderly, and individuals recovering from illness or fatigue. It also improves mineral bioavailability due to microbial fermentation (Tamang & Thapa, 2006).

**Raksi (Nepal, Darjeeling, Sikkim)** is a clear, distilled alcoholic beverage typically made from fermented rice, millet, or buckwheat. The grains are soaked, steamed, and fermented using local starter cultures. The fermented mash is then distilled using traditional pot stills to obtain a strong spirit containing approximately 22–27% alcohol . Though high in alcohol, Raksi is traditionally consumed in small quantities for its warming effect and to aid digestion, especially during cold weather or ceremonial feasts. It is believed to help with circulation and appetite stimulation (Kozaki *et al*., 2000).

**Tchang/Jhar and Rokshi (Sikkim)** are traditional tribal beverages—Tchang/Jhar being millet-based and served in bamboo cups, while Rokshi is made using ingredients like Canna edulis and maize. Both are probiotic-rich, containing Saccharomyces cerevisiae, Saccharomycopsis fibuligera, and lactic acid bacteria, supporting digestion and gut health. Both beverages are rich in probiotic microorganisms, including Saccharomyces cerevisiae, Saccharomycopsis fibuligera, and lactic acid bacteria, which aid in digestion, support gut microbiota balance, and may improve immune response. Their cultural use emphasizes their role in health maintenance within tribal communities (Sekar & Mariappan, 2007).

**Yu (Manipur)** is a traditional rice-based alcoholic beverage made by fermenting cooked rice with a herbal starter culture known as hamei. The mixture is kept in bamboo or earthen containers often lined with aromatic leaves and left to ferment naturally, resulting in a mildly alcoholic drink with a tangy-sweet flavor. Yu contains a diverse range of probiotic microbes that promote gut health, enhance digestion, and provide mild relaxation. Its low alcohol content and microbial richness make it suitable for regular cultural consumption and as a functional beverage within local diets (Singh & Singh, 2006).

**Probiotic Viability, Shelf Stability & Nutritional Quality**

Millet varieties (finger, kodo, bajra, and foxtail) exhibited enhanced antioxidant activity, increased protein content, and improved probiotic survival when fermented with *Lactobacillus, Bifidobacterium, and Streptococcus*strains (Sharma & Sharma, 2020). Fermentation not only boosted nutrient retention but also enhanced probiotic stability (Manasa *et al*., 2022). Barley-based formulations achieved exceptional probiotic counts of 8.59 log CFU/mL (Ahuja *et al*., 2017). Oat-based beverages maintained microbial stability and preserved beta-glucan content for up to 21 days (Angelov *et al*., 2006). Whey and honey incorporation increased bioactive compounds and increases functionality (Fathima *et al*., 2021). Probiotic activity in such gluten-free formulations was successfully maintained for 28 days (Ziarno *et al*., 2019). Whey pearl millet barley blends inhibited Shigella translocation, and also enhanced gut immunity (Ganguly *et al*., 2019); and flavored variants like mango enriched lassi were preferred for taste (Sabavath *et al*., 2022). Detailed Analysis of Cereal and Millet-Based Probiotic Drinks is given in Table-4.

There is a vast variability in the duration of fermentation, ranging from 4 to 48 hrs among studies due to differences in the substrate composition as well as microbial strain. Fathima & Kumar (2021) also reported that some beverages were able to maintain viability of the probiotic for more than five weeks, but it was considered another factor that was important along with storage stability. It has been shown that oats drink with Lactobacillus plantarum B28 fermentation improved viscosity, sensory acceptance and probiotic survival for 21 days (Angelov *et al*. 2006). Finger millet fermentation with Lactobacillus casei 431 resulted in a steady pH decline (0.3 units/week), stabilizing at 5.05, with retained probiotic activity after 5 weeks (Farseen *et al*., 2017). Barley-milk blends optimized fermentation using response surface methodology yielded high beta-glucan content and excellent sensory ratings (Ahuja *et al*., 2017). In Multi-millet beverages, mix of seven millet varieties produced stable, smooth-textured drinks with high probiotic viability for four weeks (Kavitha & Kiruthika, 2019). The different formulations of the beverages appear to influence the probiotic viability of the drink significantly with CFU counts documented between the range of 10⁶ to 10¹² CFU/mL.

 A *Lactobacillus acidophilus* NCDC 13 containing whey-pearl millet-barley probiotic drink was found to improve intestinal IgA levels while reducing Shigella translocation in a murine model (Ganguly *et al*., 2019). A fermented gluten-free millet drink with Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus was able to maintain allergen-free status while retaining probiotic activity for 28 days (Ziarno *et al*., 2019). A kodo millet-based drink fortified with antioxidants (53.11%), protein (24.2g), and fiber (8.3 g) was highlighted as a potential functional health beverage (Sharma & Sharma, 2020). A ready-to-drink millet beverage designed for the elderly population demonstrated good sensory acceptance and considerable antioxidant activity (Bembem & Agrahar-Murugkar, 2020). The application of prebiotic supplementation on a foxtail millet-based probiotic drink was shown to increase antioxidant effects as well as improve probiotic viability and nutrient bioavailability (Fathima & Kumar, 2021).

In order to improve the sensory properties, a finger millet-based probiotic lassi introduced mango and strawberry flavors, with the mango flavored lassi being the most accepted by the consumers (Sabavath *et al.,* 2022). A Bajra millet-based probiotic beverage showed marked post fermentation flavonoid as well as anti-oxidant activity, and it was acceptable with a 1:7 water ratio (Manasa & Sharma, 2022).

### ****Impact of Fermentation on Phenolic Content and Anti-nutritional factor**s**

Many studies have demonstrated that fermentation effectively reduces anti-nutritional factors such as phytates, oxalates, polyphenols, and lectins in cereals and millets, thereby improving their nutritional value and bioavailability. A detailed summary of effect of fermentation on anti-nutritional factors in cereal- and millet-based probiotic beverages is shown in Table-5. Several studies, including those by Saharan & Khetarpaul (2001) and Onyango et al. (2005), demonstrated a substantial reduction in phytate content, thereby enhancing mineral bioavailability, particularly iron and zinc. Lactobacillus-mediated fermentation was found to be especially effective in breaking down phytates and improving nutrient solubility (Kumar et al., 2010).

### Fermentation significantly decreased oxalate content, as seen in studies by Kalita et al. (2007) and Sreerama et al. (2012), leading to improved calcium absorption. The process also reduced polyphenols, thereby enhancing protein and starch digestibility (Katina et al., 2007). Furthermore, probiotic strains such as Lactobacillus plantarum effectively degraded lectins, contributing to improved protein digestibility (Sharma & Kapoor, 1996). This enhanced antioxidant capacity promotes better metabolic health and the prevention of chronic diseases by reducing inflammation and oxidative stress (Dey & Kuhad, 2014).

Fermentation induces key biochemical transformations that enhance the phenolic content of probiotic beverages, boosting their antioxidant potential. These changes occur through two primary mechanisms: liberation and biotransformation. Cereals and millets store phenolic compounds in three forms: **Free** (readily available), c**onjugated** (linked to sugars or other molecules) and b**ound** (tightly attached to cell wall components like lignin and polysaccharides). During fermentation, liberation of bound phenolics occur through microbial enzymes—including **esterases, xylanases, and feruloyl esterases**—break down these bonds, which release bioactive phenolic acids such as: f**erulic acid, caffeic acid and p-Coumaric acid.** This enzymatic action increases phenolic bioavailability, enhancing the beverage’s health benefits (Hole et al., 2012). Probiotic strains like Lactobacillus and Bifidobacterium further modify phenolic structures through microbial metabolism, generating derivatives with h**igher antioxidant activity, improved bio-activity and greater functional potential** (Gowd et al., 2016). The antioxidant activity of probiotic millet-based beverages is significantly increased due to the improved release and transformation of phenolics during fermentation.

Anti-nutritional factors in cereals and millets, such as phytates, oxalates, polyphenols, and lectins, can hinder nutrient absorption. Phytates bind to minerals like iron, zinc, and calcium, reducing their bioavailability (Jones *et al.,* 2017). Polyphenols interfere with enzyme activity (Singh *et al.,* 2018),while oxalates limit calcium absorption (Noel *et al.,* 2018). Lectins disrupt protein digestion (Lajolo *et al.,* 2017). However, probiotic fermentation can reduce these factors, improving nutrient bioavailability, enhancing phenolics usefulness and extractability (Singh *et al.,* 2020; Katina *et al.,* 2007). A detailed summary of Anti-Nutritional factors present in millets and cereals are mentoned in Table 6 & 7.

Fermentation not only enhances the nutritional quality of millet- and cereal-based beverages but also makes them more bioavailable and functionally beneficial for human consumption.

**IV. Discussion**

Fermentation is a biochemical process that significantly transforms the nutritional and functional characteristics of cereals and millets. During lactic acid bacteria (LAB)-mediated fermentation, microbial enzymes degrade complex macromolecules, improving nutrient bioavailability and reducing anti-nutritional factors. This enzymatic breakdown enhances protein digestibility, mineral absorption, and vitamin content (Osman, 2011). For instance, the hydrolysis of phytic acid, tannins, and oxalates increases the bioaccessibility of iron, zinc, and calcium, which are otherwise poorly absorbed due to complex formation in raw grains (Adebo et al., 2022).

LAB fermentation has been shown to improve the nutritional profile of millet varieties such as finger millet, foxtail millet, bajra, and kodo millet by increasing antioxidant activity, protein content, and dietary fiber (Sharma & Sharma, 2020). In addition, the incorporation of ingredients like honey, whey, and fruit pulp further enhances the retention of bioactive compounds and antioxidant levels in these beverages (Bembem & Agrahar-Murugkar, 2020). Controlled submerged fermentation using tofu whey medium has demonstrated a substantial increase in B-vitamin concentrations and amino acid content, along with a reduction in crude fiber, resistant starch, and glycemic index (Mohapatra et al., 2024).

These fermentation processes also lead to an increase in the concentration of essential amino acids such as lysine and methionine, which are typically limiting in unfermented millets. This enhancement is attributed to microbial biosynthesis and proteolysis during fermentation (Adebo et al., 2022). In terms of probiotic delivery, millet-based formulations are highly effective carriers due to their favorable nutrient composition. High viability levels of probiotic strains such as Lactobacillus plantarum and Streptococcus thermophilus have been achieved, ranging from 10⁶ to 10¹² CFU/mL (Ziarno et al., 2019).

These probiotics also demonstrate stability over 4 to 5 weeks under refrigerated storage, with a gradual pH decline (e.g., to ~5.05) supporting microbial survival and product safety (Farseen et al., 2017). Such beverages also deliver physiological benefits. A study on whey–pearl millet–barley blends reported an increase in secretory IgA levels and reduced Shigella translocation, suggesting improved gut immunity (Ganguly et al., 2019). Gluten-free millet formulations have also maintained allergen-free status while promoting gut microbiota balance (Ziarno et al., 2019).

Sensory acceptability plays a pivotal role in consumer acceptance. Flavored formulations, particularly those with mango, received high preference scores (Sabavath et al., 2022). Bajra and barley-based beverages, when optimized for dilution and taste, also showed favorable sensory outcomes (Manasa & Sharma, 2022). The inclusion of fruits, honey, and fermentation-controlled LAB strains improves not only palatability but also antioxidant potential and shelf life (Ahuja et al., 2017). Traditional fermentation, often practiced through back-slopping, is widely accessible and culturally rooted but presents variability in nutrient outcomes and microbial safety (Osman, 2011). While it allows for the use of natural microbiota, it lacks the consistency required for industrial-scale production and often results in less predictable reductions in anti-nutritional compounds (Adebo et al., 2022). On the other hand, lab-controlled fermentation using standardized starter cultures offers better control over microbial activity and fermentation parameters such as pH, temperature, and inoculum size (Mohapatra et al., 2024).

Controlled fermentation ensures enhanced and reproducible nutritional profiles, shorter processing durations, and improved safety. For instance, LAB fermentation of dehusked kodo millet, pearl millet, and sorghum in tofu whey media resulted in a 12.5% increase in protein content, up to 90% enhancement in amino acid profile, and significant improvement in antioxidant capacity—all achieved within 4–17 hours (Mohapatra et al., 2024). In comparison, traditional fermentation processes may require 24–72 hours and still yield less optimal outcomes.

Thus, while traditional methods hold value in rural and household settings, **lab-controlled fermentation stands out as the more efficient and nutritionally superior approach** for the development of **non-alcoholic, probiotic-rich millet beverages** that are safe, shelf-stable, and commercially scalable.

### ****V. Conclusion****

Traditional Cereal- and millet-based probiotic drink consumption should be encouraged due to its beneficial role. It’s a promising non-dairy alternative with significant nutritional, functional health benefits. Fermentation enhances the bioavailability of nutrients, improves probiotic viability, and increases antioxidant activity, making these beverages valuable for gut health, immune support, and chronic disease management. Additionally, sensory evaluations indicate high consumer acceptability, particularly for fruit-flavored variants such as mango and strawberry. Despite their potential, challenges remain in optimizing fermentation techniques, shelf-life stability, and consumer preference. Future research should focus on standardizing fermentation processes, improving storage conditions to maintain probiotic efficacy, and diversifying product formulations to enhance marketability and consumer demand. Overall, cereal- and millet-based probiotic beverages are functional foods with substantial commercial potential, requiring further innovation and research to maximize their health benefits and global market acceptance.

## **Author Contribution**

**Zainab Perveen**: Development of design, writing original draft, and visualization

**Sadia Chishty:** Conceptualization, review, editing and supervision.

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**Table 1: Macronutrient Profile of Millets and Cereals per 100g basis**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Category** | **Grains** | **Energy****(Kcal)** | **Protein****(g)** | **Carbohydrate****(g)** | **Starch****(g)** | **Fat****(g)** | **Dietary fibres****(g)** |
| Millet | Sorghum | 334 | 10.4 | 67.6 | 59 | 1.9 | 10.9 |
| Millet | Pearl millet | 363 | 11.6 | 61.7 | 55 | 5 | 11.4 |
| Millet | Finger millet | 320 | 7.3 | 66.8 | 62 | 1.3 | 11.1 |
| Millet | Proso millet | 341 | 12.5 | 70.0 | - | 1.1 | - |
| Millet | Foxtail millet | 331 | 12.3 | 60.0 | - | 4.3 | - |
| Millet | Little millet | 329 | 8.7 | 65.5 | 56 | 5.3 | 6.3 |
| Millet | Barnyard millet | 307 | 11.6 | 65.5 | - | 5.8 | - |
| Millet | Kodo | 353 | 10, 6 | 59.2 | - | 4.2 | 10.2 |
| Cereal | Wheat | 321 | 11.8 | 64.7 | 56 | 1.5 | 11.2 |
| Cereal | Rice | 353 | 6.8 | 74.8 | 71 | 0.5 | 4.4 |
| Cereal | Maize | 334 | 11.5 | 64.7 | 59 | 3.6 | 12.2 |

Source: IFCT 2017, Nutritive values of Indian Foods

**Table 2 The Vitamin and Mineral Content of Millets (mg per 100 g of Edible Portion)**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Parameter** | **Finger millet** | **Sorghum** | **Proso****Millet** | **Foxtail****Millet** | **Little****Millet** | **Kodo****Millet** | **Barnyard****Millet** | **Pearl****Millet** | **Wheat** | **Maize** | **Rice raw milled** |
| Total carotenoids | 154 | 212 | - | 32 | 120 | 272 | - | 293 | 287 | 154 | 16.9 |
| Thiamine | 0.37 | 0.35 | 0.20 | 0.59 | 0.26 | 0.29 | 0.33 | 0.33 | 0.45 | 0.33 | 0.05 |
| Riboflavin | 0.17 | 0.14 | 0.18 | 0.11 | 0.05 | 0.20 | 0.10 | 0.25 | 0.17 | 0.09 | 0.05 |
| Niacin | 1.34 | 2.1 | 2.3 | 3.2 | 1.29 | 1.49 | 4.2 | 2.3 | 5.5 | 2.69 | 1.69 |
| Calcium | 364 | 27.6 | 14 | 31 | 16.06 | 15.27 | 20 | 42 | 41 | 8.91 | 7.49 |
| Phosphorus | 283 | 274 | 206 | 290 | 220 | 188 | 280 | 296 | 306 | 279 | 160 |
| Iron | 4.61 | 3.95 | 0.8 | 2.8 | 1.26 | 2.34 | 5.0 | 8.0 | 5.3 | 2.49 | 0.65 |
| Magnesium | 137 | 1.33 | 153 | 81 | 133 | 147 | 82 | 137 | 138 | 145 | 64 |
| Sodium | 11 | 5.42 | 8.2 | 4.6 | 8.1 | 4.6 | - | 10.9 | 17.1 | 4.44 | - |
| Potassium | 408 | 3.28 | 113 | 250 | 129 | 144 | - | 307 | 284 | 291 | - |
| Copper | 0.67 | 0.45 | 1.60 | 1.40 | 0.34 | 0.26 | 0.62 | 1.06 | 0.68 | 0.45 | 0.23 |
| Zinc | 23 | 1.96 | 1.4 | 2.4 | 3.7 | 0.7 | 3.0 | 3.1 | 2.7 | 2.27 | 1.3 |

 Source: IFCT 2017, Nutritive values of Indian Foods. (\*All values in mg)

**Table 3: Comparative Analysis of Cereal- and Millet-Based Traditional Drinks**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study** | **Drink** | **Cereal/Millet Source** | **Fermentation Culture/Process** | **FHR & Temperature** | **Purification/Separation** | **CFU (Colony-Forming Units)** | **Sample Used** | **Range Specified** |
| Kolawole *et al*., 2007 | Pito (Fermented)( West Africa ) | Sorghum | Natural fermentation (Lactic Acid Bacteria & Yeast) | 48 hours soaking, 5 days malting, overnight standing, repeated boiling & cooling | Filtration using a fine mesh | ~10⁶-10⁷ CFU/mL | Sorghum malted and fermented | pH 3.5-4.5, Fermentation 24-48h |
| Kolawole *et al*., 2007 | Pito (Unfermented)( West Africa ) | Maize, Cashew & Mango bark | No fermentation | Boiling for 2 hours, steeping bark for 7 hours | Filtering the mixture | No CFU reported | Roasted maize mixed with extract | No fermentation, direct consumption |
| Arici & Daglioglu, 2002 | Boza(Central Asia) | Various grains (e.g., wheat, millet) | No fermentation (mashing & sweetening) | Cooling to ~40°C | Straining to remove solids | ~10⁶-10⁸ CFU/mL | Fermented wheat-based product | Storage 1-3 days, chilled at 4°C |
| Mugula et al., 2003 | Togwa(Tanzania) | Millet/Sorghum | Lactic acid fermentation | Ferment at 30°C for 24 hours | Sieving & concentration | ~10⁵-10⁷ CFU/mL | Fermented sorghum/millet slurry | Acidity pH 3.2-3.8, 24h fermentation |
| (Ukwuru & Ohaegbu, 2018 | Obiolo(Nigeria ) | Millet/Sorghum | Fermentation for 24 hours | Germination for 3 days, Boiling for 30 min | Sieving and cooling | ~10⁶ CFU/mL | Sprouted millet/sorghum | Fermentation 24h, temp 30°C |
| Adeyemi & Umar, 1994 | Kunu-zaki (Nigeria ) | Millet/Sorghum | Fermentation for 8 hours | 48 hours steeping | Wet sieving, decanting supernatant | ~10⁵ CFU/mL | Spiced millet/sorghum drink | Refrigerated storage needed |
| Ekundayo *et al.,* 1969 | Burukutu( West Africa ) | Sorghum | Fermentation for 48 hours | 5-day germination, 4-hour boiling | No clear separation step mentioned | ~10⁷ CFU/mL | Sorghum fermented beverage | Vinegar-like odor, cloudy consistency |
| Molin, 2003 | Ogi(Nigeria) | Corn | Fermentation for 1-3 days | Sedimentation for 1-2 days | Wet milling, sieving, sedimentation | ~10⁶ CFU/mL | Fermented corn porridge | Fermentation 24-72h, pH 3.5-4.5 |
| Molin, 2003 | ProViva(Sweden) | Oatmeal & Barley malt | Lactic acid fermentation with Lactobacillus plantarum | Cooling to 4-8°C | Blending with fruit juice or ice cream base | ~10⁷-10⁹ CFU/mL | Functional probiotic beverage | Controlled pH 3.2-3.8 |
| Abd-el-Malek *et al*., 1993; Mahmoud, 1993; Morcos, 1993 | **Kishk**(Europe) | Wheat + milk/yogurt | LAB fermentation + drying | Variable (typically days-weeks) | Sun-dried into powder/balls | Not specified | Bulgur wheat + fermented yogurt | pH ~4.0, moisture <10% |
| Campbell-Platt, 1994; Haard *et al*., 1999 | **Tarhana**(Greece ) | Wheat flour + yogurt | 1–7d fermentation (LAB: S. thermophilus, L. bulgaricus) | Ambient (25–30°C) | Dried to 6–9% moisture | Not specified | Wheat + yogurt + vegetables | pH 3.8–4.2, shelf life 1–2 years |
| Lotong, 1998; Yokotsuka & Sasaki, 1998 | **Sake**(Japa) | Polished rice | Dual fermentation (Aspergillus oryzae + yeast) | 15–20°C, 15–30days parallel saccharification | Pressing, filtration | Not applicable (alcoholic) | Rice + koji + yeast | Alcohol 15–20%, pH 4.0–4.5 |
| Escobar *et al*., 1993; Haard *et al*., 1999 | **Chicha**(South America) | Maize (corn) | Saliva-assisted saccharification + wild fermentation (S. cerevisiae, Lactobacillus, Acetobacter) | 2-7 days at ambient temp | Straining/clarification | Not quantified | Chewed corn mash | pH 3.5-4.0, alcohol 1-3% |
| Odunfa *et al*., 2001; Gadaga *et al*., 1999 | **Mahewu**(Africa) | Maize (cornmeal) + sorghum/millet malt | Spontaneous LAB fermentation (Lactococcus lactis) | 24-48h at 25-30°C | Sieving/filtration | ~10⁷-10⁸ LAB | Cornmeal-malt mixture | pH 3.5-4.0, non-alcoholic |
| Morcos *et al*., 1973, 1993 | **Bouza**(Egypt) | Wheat (partially baked loaves + malt) | Dual fermentation (LAB + wild yeast) | 3-5 days at ambient temp | Coarse filtration | Not specified | Wheat-malt mixture | pH 3.9-4.0, alcohol 2-4% |
| Zvauya *et al*., 1997 | **Mangisi**(Southern Africa) | Finger millet | Spontaneous fermentation (wild yeasts + LAB) | 24-72h at ambient temp | Straining | Not specified | Malted millet mash | pH ~4.0, moisture <10% |
| Muyanja *et al*., 2003 | **Bushera**(Uganda) | Sorghum/millet | Natural LAB (L. brevis, Lactococcus, Leuconostoc, Streptococcus) | 1-6 days at ambient temperature | Sieving | ~10⁷-10⁸ LAB | Germinated sorghum/millet flour | pH 3.5-4.0, non-alcoholic |

**Table 4: Detailed Analysis of Cereal and Millet-Based Probiotic Drinks**

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Study** | **Drink** | **Cereal/Millet Source** | **Fermentation Culture/Process** | **FHR & Temperature** | **Purification/Separation** | **CFU (Colony-Forming Units)** | **Sample Used** | **Range Specified** |
| Ghosh *et al*., 2014 | Haria (India) | Rice | Bakhar starter culture (1:100 ratio) | 3-5 days in dark earthen pots at ambient temperature | Dilution + sieving | Not quantified | Boiled/scorched rice + bakhar starter | pH: 4.0-4.5 |
| Das *et al*., 2012 | Apong (India) | Glutinous rice + ash | Epop starter (1:30 ratio) | 20 days at 30-35°C in earthen pots | Filtration | Not quantified | Cooked rice + ash + epop starter | pH: ~4.2 |
| Chakrabarty *et al*., 2014 | Judima (India | Rice | Humao starter (1:100 ratio) | 3-4 days at room temperature | Bamboo cone (khulu) filtration | Not measured | Air-dried boiled rice + humao | pH: 3.8-4.2 |
| Das *et al*., 2012 | Zutho (India) | Rice | Grist starter culture | 2-3 days at room temperature in earthen jars | Direct consumption (unfiltered) | Not reported | Cooled rice porridge + grist |  pH: ~4.0-4.5 |
| Roy *et al*., 2004 | Rice Jann (India) | Rice | Balam starter (1:125 ratio) | 6-10 months at room temperature in airtight earthen pots | Dilution + filtration | Not studied | Cooled boiled rice + balam |  pH: ~4.2-4.8 |
| Karki & Kharel, 2010 | Kodo ko jaanr (India) | Finger millet (Eleusine coracana L.) | Solid/semi-solid natural fermentation | 3-5 days at ambient temperature | Straining | ~10⁷-10⁸ LAB | Dry millet seeds + traditional starter |  Mildly alcoholic (2-3% ABV)pH: 3.8-4.2 |
| Navdeep *et al*., 2015 | **Sura (Sur)****(India)** | Finger millet (Eleusine coracana) | Natural fermentation using wild yeast & lactic acid bacteria | 3–5 days at ambient Himalayan temperatures (15–25°C) | Traditionally not purified; consumed as is | Varies; includes LAB (lactic acid bacteria) and yeast species | Fermented beverage sample | Alcohol content: ~2–5%, pH: ~3.5–4.5 |
| Shrivastava *et al*., 2012 |

|  |
| --- |
| **Shhang (Ccharo-kham)****(India)** |

 | Barley, millet, or rice | Natural fermentation using traditional starter (local yeast) | 2–4 days, ambient (20–30°C) | Filtered, no distillation | High LAB & yeast counts (probiotic-rich) | Barley+millet or barley + rice | pH 3.5-4.0, non-alcoholic |
|

|  |
| --- |
| Pintu & Verma (2019) |

 | **Rabadi**(India) | Wheat, barley, or pearl millet | Sour buttermilk mixed with cereal flour, sun-fermented | Not specified | Boiling, seasoning | Not specified | Wheat+barley/pearl millet | Regional variations |
| Tamang & Thapa (2006 | **Bhaati ka jannr**(India) | Rice | Natural fermentation using traditional starter (Marcha) | 2–3 days, ambient | Filtered, not distilled | Not specified | rice | Not specified |
| Kozaki *et al.* (2000) | **Raksi** (India) | Rice, millet, buckwheat | Fermented, then distilled (22–27% alcohol) | Not specified | Distillation | Not specified | Rice+millet+buckwheat | Not specified |
| Sekar & Mariappan (2007) | **Tchang/jhar**(India) | Millet | Fermented in bamboo vessels with natural microbes | Not specified | Filtered | Not specified | Millet  | Not specified |
| Sekar & Mariappan (2007) | **Rokshi** (India) | Maize,  | Plant-based fermentation with traditional methods | Not specified | Filtered | Not specified | Maize | Not specified |
| Singh & Singh (2006) | **Yu** (India) | Rice | Hamei starter culture, fermented in earthen pots/bamboo baskets | 2–5 days, ambient | Filtered  | Not specified | rice | Not specified |

**Table 5:Effect of Fermentation on Anti-Nutritional Factors in Cereal- and Millet-Based Probiotic Beverages**

|  |  |  |
| --- | --- | --- |
| **Study/Reference** | **Anti-Nutritional Factor** | **Effect of Fermentation** |
| Saharan & Khetarpaul (2001) | Phytates (Phytic Acid) | Reduced by 40–50% in pearl millet, improving mineral bioavailability. |
| Onyango *et al*. (2005) | Phytates (Phytic Acid) | Reduced by 72% in maize porridge through lactic acid fermentation due to microbial phytase activity. |
| Kumar *et al*. (2010) | Phytates (Phytic Acid) | Significant decrease in finger millet using Lactobacillus plantarum, increasing iron solubility. |
| Kalita *et al*. (2007) | Oxalates | Lactobacillus spp. degraded oxalates in millet-based beverages, reducing content by 50%. |
| Sreerama *et al*. (2012) | Oxalates | Traditional fermentation of finger millet significantly decreased oxalates, enhancing calcium availability. |
| Katina *et al*. (2007) | Polyphenols | Sourdough fermentation of whole-grain cereals reduced polyphenols, improving protein and starch digestibility. |
| Sharma & Kapoor (1996) | Lectins | Probiotic fermentation of sorghum and millet flours degraded lectins, enhancing protein digestibility. |

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Millets** | **Phytate** | **Polyphenols** | **Oxalates** | **Tannins** | **Saponins** | **Cyanogenic glycosides** |
| Pearl millet | 0.6% - 1.8% | 0.5% - 2.0% | 0.2% - 0.5% | 0.2% - 0.5% | 0.1% - 0.3% | - |
| Finger millet | 0.8% - 2.0% | 1.0% - 3.0% | 0.2% - 0.5% | 0.2% - 0.5% | 0.3% - 0.8% | - |
| Foxtail millet | 0.5% - 1.5% | 0.5% - 2.0% | 0.2% - 0.5% | 0.2% - 0.5% | 0.1% - 0.3% | - |
| Proso millet | 0.6% - 1.8% | 0.5% - 2.0% | Not mentioned | Not mentioned | Not mentioned | - |
| Barnyard millet | 0.5% - 1.5% | 0.5% - 2.0% | Not mentioned | Not mentioned | 0.1% - 0.3% | - |
| Kodo millet | 0.6% - 1.8% | 0.5% - 2.0% | 0.5% - 2.0% | Not mentioned | Not mentioned | - |
| Little millet | 0.8% - 2.0% | 0.5% - 2.0% | Not mentioned | 0.2% - 0.5% | Not mentioned | 0.01% - 0.1% |

 **Table 6: Anti-Nutritional Factors in Millets**

**Source:** Adapted from Jones et al. (2017), Singh et al. (2018), Noel et al. (2018), Lajolo et al. (2017) & Katina et al. (2007)

 **Table 7: Anti-Nutritional Factors In Cereals**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Cereals** | **Phytate** | **Polyphenols** | **Oxalates** | **Tannins** | **Saponins** |
| Wheat | 0.4-1.4% | 0.5-2.0% | 0.1-0.5% | 0.1-0.4% | 0.1-0.5% |
| Barley | 0.5-1.6% | 0.8-3.0% | 0.2-0.6% | 0.2-0.6% | 0.2-0.6% |
| Oats | 0.6-1.8% | 1.0-4.0% | 0.3-0.8% | 0.3-0.8% | 0.3-0.% |
| Rice | 0.2-0.8% | 0.2-1.0% | 0.1-0.3% | 0.1-0.3% | 0.1-0.3% |
| Maize | 0.5-1.5% | 0.5-2.0% | 0.2-0.5% | 0.2-0.5% | 0.2-0.5% |

 **Source:** Adapted from D’Mello (2000) and Reddy & Pierson (1994)