***Review Article***

**A Comprehensive Review on 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 that supports for a healthy gut, good digestion and increased antioxidant activity.

**Methods:** Several studies on cereal and millet based traditional and recent probiotic drink were extensively reviewed 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).

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).

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.

Clinical and experimental evidence suggests that such probiotic formulations can contribute to the prevention and management of chronic conditions such as cardiovascular disease, type 2 diabetes, and obesity. 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)

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 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. Predominantly from the Lactobacillus and Bifidobacteriumgenera, these microorganisms can function individually or synergistically to support various physiological processes.

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). 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).

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.

In the context of food-based delivery systems, cereals and millets offer an excellent medium for probiotic fermentation. Their natural abundance of carbohydrates, proteins, vitamins, and minerals supports microbial growth and activity during the fermentation process (Das et al., 2020). Particularly, millets such as finger and pearl millet are noted for their higher dietary fiber and mineral concentrations compared to conventional grains, making them especially valuable for functional beverage development (Luana et al., 2017).

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).

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. The fermentation process with Lactobacillus plantarum enhances its protein digestibility, making it suitable for infant nutrition. 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).

Togwa (Tanzania) is a porridge-like beverage made from cereals or cassava, naturally fermented with lactic acid bacteria and yeasts. It is a staple in rural diets and is appreciated for its contribution to child nutrition and digestive health. Togwa has a moderate shelf life and is often consumed as a functional beverage. (Lorri & Svanberg, 1995).

ProViva (Sweden) is a commercially produced oat-based probiotic drink containing L. plantarum 299v. 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).

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 (Arici & Daglioglu, 2002).

 Pito (West Africa) is a mildly alcoholic beverage made from fermented sorghum, commonly consumed in Nigeria and Ghana during social gatherings and ceremonies. Despite its rich cultural value, its shelf life is short and its alcohol content makes it unsuitable for children. It is often brewed locally and consumed fresh(Kolawole *et al*., 2007).

Obiolo (Nigeria) is a non-alcoholic, smooth millet or sorghum-based drink, enriched with probiotics through traditional fermentation. It is valued for its mild taste and health benefits, especially in improving gut health and child nutrition. Obiolo is commonly used in homes and has a relatively short shelf life (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. It plays a key role in adult social events and ceremonies, but its alcohol content and perishability limit its broader use. It is traditionally brewed and consumed within a short period (Ekundayo *et al*., 1969).

Kunu-Zaki (Nigeria) is a sweet-sour, non-alcoholic millet-based drink consumed by both children and adults. It is used as a weaning food and is also a popular street refreshment. With moderate shelf life and high acceptability, it supports hydration and nutritional needs in warm climates (Adeyemi & Umar, 1994).

Kishk (Middle East, Europe) is a dried fermented blend of wheat and yogurt, rich in B vitamins and minerals. 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(Abd-el-Malek & Demerdash, 1993). Tarhana (Greece, Turkey) is a dried mixture of fermented wheat, yogurt, and vegetables, typically rehydrated and used in soups. Its drying process extends shelf life significantly, combining fermentation with preservation(Campbell-Platt *et al*., 1994).

Sake (Japan, China) is a traditional rice wine made using Aspergillus oryzae, lactic acid bacteria, and yeasts. It undergoes a complex fermentation and holds ceremonial importance in East Asian cultures. As an alcoholic beverage, it is not suitable for all age groups but is valued for its craftsmanship and cultural depth. (Lotong *et al*., 1998).

Chicha (South America) is a mildly alcoholic corn drink made using a traditional method that involves chewing or mashing maize to begin fermentation. It contains probiotic microorganisms and is consumed during rituals and communal gatherings. Chicha reflects indigenous knowledge and serves as a functional, social drink(Escobar *et al*., 1993).

Mahewu (Africa, Arabian Gulf) is a fermented cornmeal drink, non-alcoholic and slightly acidic, made with lactic acid bacteria. It is consumed as a weaning food or energy drink and is particularly refreshing in hot climates. Its shelf life is short unless refrigerated, but it is rich in probiotics(Odunfa *et al*., 2001).

Bouza (Egypt, Turkey, Eastern Europe) is one of the oldest known fermented drinks, made from malted wheat. It is tangy and mildly alcoholic, often prepared at home using traditional methods. Bouza has historical importance and is considered a cultural heritage drink with moderate shelf stability (Morcos *et al*., 1973).

Mangisi (Africa) is a millet-based fermented drink used both in weaning and celebrations. It has a mild alcohol content and aids digestion through its probiotic content. Mangisi is seasonally produced and consumed fresh, making it a versatile yet perishable drink(Zvauya *et al*., 1997).

Bushera (Uganda) is a sour-tasting, fermented drink made from millet or sorghum, traditionally prepared at home. It is high in probiotics and commonly consumed by children and adults alike. Bushera supports gut health and is integral to Ugandan food culture, though its shelf life is limited(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 tangy, wholesome fermented milk drink made by combining cereal flour with sour buttermilk, sun-fermenting, boiling, and seasoning. Known for its taste and nutritional value, it remains a cherished homemade delicacy with a short shelf life (Pintu & Verma, 2019).

**Haria (West Bengal & East-Central India)** is a traditional rice beer fermented in earthen pots using boiled rice and bakhar (a herbal starter). It contains beneficial yeasts like Saccharomyces spp., lactic acid bacteria, and antioxidants, serving as both food and natural remedy among tribal communities (Ghosh *et al*., 2014).

**Apong (Arunachal Pradesh)** is prepared using cooked glutinous rice mixed with ash from paddy husk and straw, and fermented with the traditional epop starter for about 20 days. It exhibits antimicrobial, antioxidant, and anti-aging properties, and may prevent kidney stones, making it a valuable functional food (Das *et al*., 2012).

**Judima (Assam)** is a fragrant, mildly sweet rice beer made from sticky rice and humao starter culture. Deeply ingrained in Dimasa rituals, it contains Saccharomyces cerevisiae and digestive enzymes that support postpartum and elderly health (Chakrabarty *et al*., 2014).

**Zutho (Nagaland)** is another fermented rice beverage made with a grist starter and fermented for 2–3 days. It is believed to regulate insulin levels, improve appetite, support wound healing, and boost immunity (Das *et al*., 2012).

**Rice Jann (Himalayan regions)** is fermented with balam starter for 6–10 months and is vital for warmth and nourishment in cold climates (Roy *et al*., 2004). **Kodo ka Jaanr (Himalayan regions)** is a finger millet-based beverage rich in iron, calcium, and B vitamins, used especially as a restorative tonic for postpartum women and the sick (Thapa & Tamang, 2004).

**Sur or Sura (Himachal Pradesh & Uttarakhand)** is another finger millet-based alcoholic drink with B vitamins, essential amino acids, antioxidants, and probiotic potential, traditionally used to aid digestion and energy recovery (Navdeep *et al*., 2015).

 **Shhang or Ccharo-Kham (Arunachal Pradesh)** is a barley-based alcoholic beverage fermented using indigenous microbial cultures, reflecting the rich fermentation heritage of the Karbi tribe (Shrivastava *et al*., 2012).

**Bhaati Jaanr (Sikkim, Darjeeling)** is a mildly alcoholic, sweet-sour rice drink loaded with probiotics and minerals like calcium, iron, and potassium, especially valued for postpartum care and elderly nutrition (Tamang & Thapa, 2006).

**Raksi (Nepal, Darjeeling, Sikkim)** is a distilled alcoholic beverage (22–27% alcohol) made from rice, millet, or buckwheat, often consumed during festivals and rituals for its digestive and warming properties (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 (Sekar & Mariappan, 2007).

**Yu (Manipur)** is a mildly alcoholic rice beverage made by fermenting cooked rice with hamei (starter) in earthen or bamboo containers lined with aromatic leaves. Its tangy-sweet taste and diverse microbial flora make it a culturally significant drink with probiotic benefits (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.

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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 |

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| **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 |
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| 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**

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| --- | --- | --- |
| **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. |

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| **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**

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| --- | --- | --- | --- | --- | --- |
| **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)