Int. J. Sci. R. Tech., 2026 3(11)
A Multidisciplinary peer-reviewed Journal
www.ijsrtjournal.com [ISSN: 2394-7063]

Original Article

Quality Characteristics and Storage Stability of Fermented Cereal-Based Beverages Produced Using a Curd-Derived Undefined Mixed Starter Culture

Vaidehi Mande*, Sneha Karadbhajne

Department of Food Technology, L.I.T, Rashtrasant Tukadoji Maharaj.

ABSTRACT

This study evaluated the quality characteristics and storage stability of fermented cereal-based beverages prepared from white rice, red rice, germinated finger millet, pearl millet, sorghum and barley using a curd-derived undefined mixed starter culture. The starter cultures were propagated separately in the corresponding cereal substrates using curd as the microbial source and sugar as a fermentable substrate. Beverage formulations containing almond milk and/or pumpkin seed milk were standardized sequentially and fermented at 37 °C. Starter concentration was selected from 1–5% (v/v) using fermentation time, pH, titratable acidity, total soluble solids (TSS), presumptive lactic acid bacteria (LAB) counts and trained-panel sensory acceptability as combined criteria. Selected starter levels were 5% (v/v) for white rice–almond, finger millet–oat and barley–oat beverages and 4% (v/v) for red rice–almond, pearl millet–oat and sorghum–oat beverages. The standardized beverages showed pH values of 4.45–4.56, titratable acidity of 0.741–0.811% lactic acid, TSS of 9.79–11.69 °Brix and viscosity of 27.70–35.24 cP. Microorganisms recovered on de Man, Rogosa and Sharpe (MRS) agar are reported as presumptive LAB because the microorganisms present in the curd-derived undefined mixed starter cultures were not isolated, identified or functionally characterized. Refrigerated storage showed greater stability than ambient storage under the tested conditions. The results support the technological potential of cereal and millet matrices for fermented plant-based beverage development, but do not establish strain-specific probiotic functionality or a validated commercial shelf life.

Keywords: fermented cereal-based beverage, curd-derived undefined mixed starter culture, lactic acid bacteria, millet, physicochemical properties, storage stability

INTRODUCTION

Plant-based fermented beverages are increasingly investigated as non-dairy food systems because cereals, millets, nuts and seeds provide fermentable carbohydrates, proteins, dietary fibre, minerals and bioactive compounds. Fermentation by lactic acid bacteria can modify acidity, flavour, texture and nutrient availability; however, the magnitude of these effects depends on the substrate, processing conditions and microbial community involved [2,3,6,8,11–15].

Rice is a major starch-rich cereal, while pigmented rice varieties may additionally contribute phenolic compounds and minerals. Finger millet, pearl millet and sorghum are nutritionally relevant millet matrices, whereas barley and oats are true cereals with fibre fractions that can influence hydration and beverage structure. Germination activates endogenous fermented cereal-based beverages and MRS-agar counts as presumptive LAB rather than probiotic counts [1].

Although cereal-based fermented beverages have been widely studied, comparatively fewer studies have examined a common curd-derived undefined mixed starter approach across multiple rice, millet and barley matrices together with plant-milk incorporation, formulation standardization, trained-panel sensory assessment and storage stability. The objective was therefore to standardize six fermented cereal-based beverages and evaluate their physicochemical, nutritional, microbiological, sensory and storage characteristics while explicitly recognizing the limitations of an undefined starter culture. The hydrolytic enzymes and may alter starch and protein characteristics, while subsequent fermentation can further modify carbohydrate availability, acidity and sensory properties [8,11,12].

Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

In this study, curd was used as the initial source of an undefined mixed microbial inoculum. This inoculum was propagated separately in the corresponding cereal slurries to produce cereal-specific, curd-derived undefined mixed starter cultures, which were subsequently used for beverage fermentation. Thus, the curd itself and the cereal-propagated starter cultures are distinct experimental materials. The microorganisms were not purified, identified to species or strain level, or tested for strain-specific health benefits. Accordingly, the products are described as Nagpur University, Nagpur, Maharashtra, India

MATERIALS AND METHODS

2.1 Raw materials and preparation

White rice (Oryza sativa L.), red rice (Oryza sativa L.), finger millet (Eleusine coracana (L.) Gaertn.), pearl millet (Cenchrus americanus (L.) Morrone; synonym Pennisetum glaucum (L.) R. Br.), sorghum (Sorghum bicolor (L.) Moench) and barley (Hordeum vulgare L.) were procured from the local market in Nagpur, Maharashtra, India. Oats, guar gum, almonds, pumpkin seeds, vanilla essence, sugar and spices used for beverage formulation were also obtained from the local market.

Almond and pumpkin seed milks were prepared separately. For each material, 100 g was cleaned, washed and soaked in 500 mL water (1:5, w/v) for 12 h at room temperature. After draining, the material was blanched at 75 ± 5 °C for 3 min. Almond skins were removed manually. The pretreated almonds and pumpkin seeds were separately blended with fresh water at 1:5 (w/v) for 5 min and filtered through muslin cloth. Stabilizer (0.2%, w/v) was added, followed by homogenization at 8000 rpm for 5 min. The plant milks were heat-treated at 85 °C for 10 min, cooled to 4–6 °C and refrigerated until use.

White and red rice bases were prepared independently. For each rice type, 100 g was washed and soaked in water at 1:5 (w/v) for 12 h at room temperature. The soaking water was discarded, and the rice was cooked until soft, cooled and wet-ground with water at 1:5 (w/v) for 3–5 min. The slurry was filtered, guar gum (0.5%, w/v) was incorporated, and the rice base was heat-treated at 85 °C for 10 min, cooled and refrigerated until use. The processing route used for beverage preparation differed from that used for starter propagation because the two materials served different technological purposes. For starter preparation, soaked rice was drained, dried and milled to obtain a storable, uniformly dispersible flour matrix that could be reconstituted at a defined flour-to-water ratio for cereal-specific microbial propagation. In contrast, rice intended for the beverage base was cooked before wet grinding to soften and gelatinize the starch-rich grains and produce the smooth aqueous base required for beverage formulation. These two processing routes were selected empirically during preliminary product-development trials and were not experimentally compared; therefore, the study does not claim that one processing route is superior to the other.

For germinated cereal flour preparation, finger millet, pearl millet, sorghum and barley were processed separately. Cleaned grains were soaked in water at 1:5 (w/v) for 24 h. Barley was germinated for 24 h, whereas finger millet, pearl millet and sorghum were germinated for 48 h. Germinated grains were dried at 40 °C, rootlets were removed manually, and 50 g oats was incorporated into each dried germinated cereal batch before milling to ≤100 µm. The resulting finger millet–oat, pearl millet–oat, sorghum–oat and barley–oat blends were stored in airtight containers until use.

2.2 Preparation and empirical selection of curd-derived undefined mixed starter cultures

Curd-derived undefined mixed starter cultures were prepared separately for white rice, red rice, finger millet, pearl millet, sorghum and barley. Curd was used only as the initial microbial inoculum. For rice starter substrates, white and red rice were soaked separately in distilled water at 1:2 (w/v) for 12 h at 30 ± 2 °C, drained, tray-dried to below 12% moisture and milled into flour. For millet and barley starter substrates, the corresponding germinated cereal flours were used. Each cereal flour was separately dispersed in distilled water at 1:5 (w/v) to obtain a uniform slurry. Following addition of curd and sugar and incubation, the resulting cereal-propagated cultures constituted the starter cultures subsequently used for beverage fermentation; curd itself was not used directly to inoculate the final beverage formulations.

Starter-condition screening was conducted separately for each cereal substrate using three curd concentrations (1, 5 and 10%, w/w), two sugar concentrations (1 and 2%, w/w) and two incubation durations (12 and 24 h) at 37 °C. pH, titratable acidity, presumptive

LAB counts on MRS agar and visible fermentation characteristics were recorded. The 5% (w/w) curd, 1% (w/w) sugar and 12 h condition was retained for subsequent starter preparation because it showed the experimentally selected combination of acid development, recovery of a substantial presumptive LAB population and clear visible fermentation within 12 h, without requiring the longer 24 h incubation. No formal numerical cut-off, weighted scoring system, response-surface model or other multi-response optimization procedure was applied. Accordingly, this stage is described as empirical screening and selection rather than formal optimization.

Curd served as the initial source of the undefined mixed microbial inoculum, sugar as an additional fermentable substrate and the cereal slurry as the propagation matrix. The cereal-propagated cultures were subsequently used as the starters for beverage fermentation. The available study records do not document whether the curd was commercially or traditionally prepared and do not establish whether a single curd batch was used for all cereal starter preparations. This information is therefore reported as unavailable rather than inferred. Because the curd microbiota was not characterized, possible variation in microbial composition among curd sources or batches could have influenced fermentation behaviour and comparability among cereal-specific starters; this is acknowledged as a limitation of reproducibility. Because microorganisms recovered on MRS agar were not isolated, purified or identified to species or strain level, viable counts are reported as presumptive LAB counts rather than probiotic counts. Prepared cereal-propagated starter cultures were maintained at 4 ± 1 °C and used within 24–48 h.

2.3 Beverage formulation and process standardization

The rice- and sprouted millet-based beverage formulations were standardized using a sequential one-factor-at-a-time approach. At each stage, one formulation variable was evaluated while the previously selected components were maintained at their selected levels. Selection was based primarily on trained-panel sensory acceptability, together with physical stability and fermentation characteristics, including pH, titratable acidity (TA), total soluble solids (TSS), and presumptive lactic acid bacteria (LAB) counts.

For the white rice–almond and red rice–almond beverages, the rice base and almond milk were evaluated at ratios of 100:0 (control), 90:10, 80:20, 70:30, 60:40, and 50:50 (v/v), maintaining a total base volume of 100 mL. Cinnamon powder was subsequently evaluated at 0.5, 1.0, 1.5, 2.0, and 2.5% (w/v), guar gum at 0.1, 0.5, 1.0, 1.5, and 2.0% (w/v), and vanilla essence at 0.10, 0.20, 0.25, 0.30, and 0.40 mL/100 mL. The white rice and red rice formulations were standardized independently.

For the finger millet–oat, pearl millet–oat, sorghum–oat, and barley–oat beverages, six cereal blend–plant milk combinations were evaluated: 100:0 (control), 90:10, 80:20, 70:30, 60:40, and 50:50. These corresponded to 100 g cereal–oat blend without plant milk, 90 g blend + 10 mL plant milk, 80 g blend + 20 mL plant milk, 70 g blend + 30 mL plant milk, 60 g blend + 40 mL plant milk, and 50 g blend + 50 mL plant milk, respectively. Almond milk and/or pumpkin seed milk was incorporated according to the respective beverage formulation. The respective spice powder was evaluated at 1.0, 2.5, 5.0, 7.5, and 10.0 g per formulation, followed by salt at 0.5, 1.0, 1.5, 2.0, and 2.5 g per formulation and guar gum at 0.5, 1.0, 1.5, 2.0, and 2.5% (w/v). Following selection of the ingredient composition, the curd-derived undefined mixed starter culture was evaluated at concentrations of 1, 2, 3, 4, and 5% (v/v), corresponding to 1–5 mL of starter culture per 100 mL of beverage. Starter concentration was selected based on the combined response of fermentation time, pH, titratable acidity (% lactic acid), TSS (°Brix), presumptive LAB counts, and trained-panel sensory acceptability.

The beverage processing sequence consisted of preparation of the cereal and plant-milk base, formulation and mixing, followed by heat treatment at 85 °C for 10 min. The heat-treated beverage base was cooled to approximately 37 °C before inoculation with the curd-derived undefined mixed starter culture. Thus, the starter culture was added only after heat treatment and cooling to avoid thermal inactivation of the fermentative microorganisms. Following inoculation, the beverages were fermented at 37 °C until the formulation-specific fermentation endpoint was reached. The fermented beverages were subsequently cooled and subjected to physicochemical, microbiological, and sensory analyses and storage studies. Based on the standardization trials, a starter concentration of 5% (v/v) was selected for the white rice–almond,

finger millet–oat, and barley–oat beverages, whereas 4% (v/v) was selected for the red rice–almond, pearl millet–oat, and sorghum–oat beverages.

2.4 Physicochemical and proximate analyses

The proximate composition of the cereal raw materials and standardized beverage samples was determined using standard methods of the Association of Official Analytical Chemists (AOAC) [16]. Moisture content was determined according to AOAC 925.10, crude protein according to AOAC 920.87, crude fat according to AOAC 920.39, and ash according to AOAC 923.03. Total dietary fibre was determined using the enzymatic–gravimetric method according to AOAC 985.29.

Available carbohydrate by difference was calculated after separately determining total dietary fibre. Because dietary fibre was subtracted from the proximate sum, the calculated fraction is termed "available carbohydrate by difference" rather than "total carbohydrate":

Available carbohydrate by difference (%) = 100 − [moisture (%) + protein (%) + fat (%) + ash (%) + total dietary fibre (%)].

Energy was calculated using Atwater conversion factors: Energy (kcal/100 g) = [protein (g) × 4] + [available carbohydrate by difference (g) × 4] + [fat (g) × 9] and converted to kJ/100 g using 1 kcal = 4.184 kJ.

The physicochemical properties evaluated included pH, titratable acidity (TA), total soluble solids (TSS), and viscosity. The pH was measured using a calibrated digital pH meter. Titratable acidity was determined by titration with standardized 0.1 N NaOH using phenolphthalein as the endpoint indicator and expressed as percentage lactic acid (% LA). Total soluble solids were determined using a refractometer and expressed as °Brix. Viscosity was measured at 25 °C using a Brookfield LV viscometer equipped with spindle No. 2 at 50 rpm and expressed in centipoise (cP).

Analyses were performed for three independently prepared production batches (n = 3), and the results were expressed as mean ± standard deviation (SD). Where replicate analytical measurements were performed within an individual batch, these were treated as technical replicates and not as independent experimental replicates.

2.5 Microbiological evaluation

Beverage and curd samples were aseptically homogenized and serially diluted in sterile peptone water before microbiological analysis. Presumptive lactic acid bacteria (LAB) were enumerated by spread-plating appropriate decimal dilutions on de Man, Rogosa and Sharpe (MRS) agar. Plates were incubated anaerobically at 37 °C for 72 h. Colonies on countable plates were enumerated and the results were expressed as colony-forming units per millilitre (CFU/mL). Because the microorganisms recovered on MRS agar were not purified or identified to species or strain level, these counts are reported as presumptive LAB counts and not as probiotic counts. Total aerobic microbial count (standard plate count) was determined according to ISO 4833-1:2013 [17]. Appropriate decimal dilutions were inoculated in Plate Count Agar (PCA) using the pour-plate technique and incubated aerobically at 30 °C for 72 h. Colonies on countable plates were enumerated and reported as CFU/ml.

Coliforms were enumerated according to ISO 4832:2006 [18] using the colony-count technique. Appropriate decimal dilutions were inoculated in Violet Red Bile Lactose (VRBL) agar by the pour-plate method and incubated aerobically at 37 °C for 24 ± 2 h. Typical coliform colonies were counted, and the results were expressed as CFU/mL. When no characteristic colonies were detected at the lowest dilution examined, the result was recorded as not detected (ND) under the analytical conditions used. Yeasts and moulds were enumerated according to ISO 21527-1:2008 [19] for products with water activity greater than 0.95. Appropriate decimal dilutions were surface plated on Potato Dextrose Agar (PDA) and incubated aerobically at 25 ± 1 °C for 5 days. Yeast and mould colonies were enumerated separately when morphologically distinguishable and expressed as CFU/mL. When no colonies were detected at the lowest dilution examined, the result was reported as not detected (ND) under the analytical conditions used.

2.6 Sensory evaluation

Sensory evaluation was conducted using nine trained adult panellists (five females and four males), aged 25–40 years. Panellists were selected based on their familiarity with cereal-based beverages, ability to discriminate relevant sensory attributes, willingness

to participate, and absence of known allergies to the ingredients used in the beverage formulations. Prior to evaluation, the panellists were familiarized with the sensory evaluation procedure, the attributes under assessment, and the use of the nine-point hedonic scale. The evaluated attributes included colour/appearance, aroma, flavour, taste, body/texture, and overall acceptability. Sensory evaluation was performed on freshly fermented beverages prior to the storage study. Approximately 25 mL of each beverage was served at 10 ± 2 °C in clean glass containers identified using randomly assigned three-digit codes. The order of sample presentation was randomized to minimize order and carry-over effects, and potable water was provided for palate cleansing between successive samples. The evaluation was conducted in three independent sensory sessions under comparable testing conditions.

The trained panel was used to provide a controlled comparative assessment of sensory acceptability among the experimental beverage formulations during product standardization. Therefore, the sensory findings are interpreted as trained-panel sensory acceptability and not as representative of broader consumer preference.

The sensory assessment involved adult volunteers and was limited to the non-invasive evaluation of food beverage samples using a nine-point hedonic scale. No clinical intervention, biological specimen collection, or collection of sensitive personal information was undertaken. Participation was entirely voluntary, and the nature and purpose of the sensory evaluation were explained to all panellists before participation. Informed consent was obtained from each panellist prior to the sensory sessions. Formal ethical approval was not sought or obtained at the time the study was conducted, and no formal exemption determination was obtained from an institutional ethics committee.

2.7 Storage stability

The storage stability of the standardized fermented cereal-based beverages was evaluated using three independently prepared production batches of each beverage formulation (n = 3). Each batch was prepared and fermented independently under the standardized processing conditions. Following fermentation, the beverages were thoroughly mixed to ensure sample homogeneity and aseptically transferred into sterilized screw-capped glass bottles. Separate bottles were maintained for each storage condition and sampling interval to minimize repeated handling and the risk of cross-contamination.

Microbiological stability during storage was assessed at the specified sampling intervals using the procedures described in Section 2.5. Presumptive LAB were enumerated on MRS agar and yeasts and moulds were enumerated on PDA, with results expressed as CFU/mL. When no yeast or mould colonies were detected at the lowest dilution examined, the result was reported as not detected (ND) under the stated analytical conditions. Coliform analysis was performed as a hygiene-indicator assessment of the fresh standardized beverages and is reported in Table 7; coliforms were not included as a repeated storage parameter. Thus, the microbiological parameters followed during storage were presumptive LAB and yeast/mould populations.

All experiments were conducted using three independently prepared production batches of each beverage formulation (n = 3), with each independently prepared batch considered the experimental unit. Statistical analyses were performed using IBM SPSS Statistics version 26.0 (IBM Corp., Armonk, NY, USA), and data are reported as mean ± standard deviation (SD). For formulation-standardization experiments, formulation or treatment level was considered the fixed factor, and differences among treatments were evaluated by ANOVA followed by Duncan's multiple range test when a significant overall effect was observed ($p < 0.05$). For the storage-stability study, the same three independently prepared production batches constituted the experimental units. Separate bottles from each batch were allocated to each storage interval to avoid repeated opening of the same container; however, observations at successive storage times originated from the same production batches and were therefore not treated as additional independent biological replicates. Refrigerated and ambient storage datasets were evaluated separately because they followed different sampling schedules. The original storage analysis examined beverage formulation, storage time, and their interaction; however, production batch was not explicitly modelled as a random or blocking factor, and a repeated-measures or mixed-effects model was not performed. Consequently, the storage data are interpreted primarily

descriptively as temporal trends across the three independent batches, and no inferential claim based on independence of the individual time-point observations is made. This statistical limitation is considered when interpreting the storage-stability findings. For sensory evaluation, beverage formulation was treated as the principal fixed factor, while panellist and sensory session were incorporated into the statistical model to account for variability associated with individual panellists and the three independent evaluation sessions.

RESULTS AND DISCUSSION

3.1 Market curd sample analysis

3.1.1 Selection and evaluation of market curd as a source of curd-derived undefined mixed starter culture

Table 1: Physicochemical Analysis of Curd

pH	Titratable acidity	TSS	Viscosity	Moisture	Fat	Protein	Ash
	%	^{0}Brix	cP	%	%	%	%
4.660.029	0.7400.080	10.90.009	18990.106	87.90.098	4.260.035	5.010.065	0.910.018

The physicochemical and proximate characteristics of the curd used for preparation of the curd-derived undefined mixed starter culture are presented in the table. The curd exhibited a pH of 4.66 ± 0.029 and titratable acidity of 0.740 ± 0.080%. The reduction in pH and development of acidity in fermented milk are primarily associated with the metabolic activity of lactic acid bacteria, which convert lactose into lactic acid during fermentation. Acidification also contributes to casein aggregation and development of the characteristic structure and consistency of fermented dairy products [20,21].

The total soluble solids (TSS) of the curd were 10.9 ± 0.009 °Brix, while the viscosity was 1899 ± 0.106 cP. The relatively high viscosity reflects the semi-solid gel structure of curd resulting from acid-induced aggregation of milk proteins. The rheological characteristics of fermented milk products are influenced by several factors, including milk composition, total solids, starter culture activity, fermentation conditions and interactions among the protein components of the gel matrix [22,23].

The curd contained 87.9 ± 0.098% moisture, indicating that water constituted the major component of the product. The fat and protein contents were 4.26 ± 0.035% and 5.01 ± 0.065%, respectively, while the ash content was 0.91 ± 0.018%. Protein and fat contribute to the nutritional value as well as the structural and sensory properties of fermented milk, whereas ash represents the overall mineral fraction of the product. Variations in these components may occur depending on the composition of the original milk, standardization practices, fermentation conditions and processing method [24,21]. Overall, the observed acidic pH, titratable acidity and semi-solid consistency confirmed that the curd had undergone characteristic lactic acid fermentation. Its physicochemical and compositional characteristics supported its subsequent use as the microbial source for preparation of the curd-derived undefined mixed starter culture used in the fermented cereal- and millet-based beverages.

3.1.2 Microbial analysis of the market curd sample

Table 2: Microbial Characteristics of the Market Curd Sample

Coliform	SPC	LAB	Y/M
$\log_{10}$ CFU/mL	$\log_{10}$ CFU/mL	$\log_{10}$ CFU/mL	$\log_{10}$ CFU/mL
ND	$3.1x10^3$	$22\ x10^5$	ND

The microbial quality of the curd used for preparation of the curd-derived undefined mixed starter culture was evaluated by determining the standard plate count (SPC), lactic acid bacteria (LAB) count, yeast and mould count, and presence of coliforms. The SPC was 3.1 × 10^3 CFU/mL, corresponding to 3.49 $\log_{10}$ CFU/mL, while the LAB count was 2.2 × 10^6 CFU/mL, corresponding to 6.34 $\log_{10}$ CFU/mL. Coliforms and yeast and mould were not detected in the analysed curd sample [25,26]. The relatively high LAB population demonstrated the presence of a substantial viable lactic acid bacterial population in the

curd. LAB constitute an important microbial group in fermented dairy products and are primarily responsible for acid production during fermentation. Their metabolic activity contributes to the development of acidity, flavour and texture and may also improve microbial stability through the production of organic acids and other antimicrobial metabolites [27,28]. The LAB count of 6.34 $\log_{10}$ CFU/mL further supported the selection of curd as a microbial source for preparation of the curd-derived undefined mixed starter culture. However, direct comparison between the LAB count and SPC should be interpreted cautiously because these microbial groups are enumerated using different media and incubation conditions. Therefore, the higher LAB count indicates efficient recovery of viable LAB under the selective enumeration conditions rather than conclusively demonstrating that LAB constituted the entire dominant microbial population. Coliforms were not detected in the analysed curd sample, indicating the absence of detectable coliform contamination under the conditions of analysis. Similarly, yeast and mould were not detected, suggesting a low fungal load in the sample. The acidic environment created by LAB and the production of antimicrobial metabolites may contribute to suppression of undesirable microorganisms in fermented dairy products [29,30].

Overall, the substantial viable LAB population, together with the absence of detectable coliforms and yeast and mould, supported the use of the curd as the microbial source for preparation of the curd-derived undefined mixed starter culture used in subsequent fermentation trials.

3.2 Fermentation characteristics and starter culture selection

The fermentation characteristics of the selected cereal-based beverage formulations are presented in Table 3. The selected curd-derived undefined mixed starter culture concentration varied according to the beverage matrix, with 5% (v/v) used for the white rice –almond, finger millet–oat, and barley–oat beverages and 4% (v/v) for the red rice–almond, pearl millet–oat, and sorghum–oat beverages. At 37 °C, the formulations reached their selected fermentation endpoints within 6.0–8.5 h. At these endpoints, pH ranged from 4.38 ± 0.022 to 4.56 ± 0.014, titratable acidity from 0.74 ± 0.011 to 0.88 ± 0.231% lactic acid, and TSS from 9.62 ± 0.038 to 11.10 ± 0.036 °Brix. The white rice–almond beverage exhibited the lowest pH and highest titratable acidity, indicating comparatively greater acid development, whereas the pearl millet–oat beverage required the longest fermentation time (8.5 h). Finger millet–oat and sorghum–oat reached their selected endpoints within 6.0 h.

Presumptive LAB counts at the selected fermentation endpoints ranged from 2.8×10^9 to 1.2×10^{10} CFU/mL. The highest numerical count was observed in the finger millet–oat beverage (1.2×10^{10} CFU/mL), followed by sorghum–oat (8.9×10^9 CFU/mL) and pearl millet–oat (7.6×10^9 CFU/mL). The observed variation in fermentation time, acidification, TSS, and presumptive LAB counts indicates that the fermentation response was dependent on the composition of the beverage matrix. Differences in fermentable substrate availability, nutrient composition, and buffering capacity may have contributed to the observed responses. Therefore, the final starter concentration was selected separately for each formulation based on the combined assessment of fermentation time, pH, titratable acidity, TSS, presumptive LAB counts, and trained-panel sensory acceptability rather than on LAB count alone. Because the curd-derived undefined mixed starter culture consisted of an undefined mixed microbial population and strain-level identification was not performed, viable counts obtained on MRS agar are reported as presumptive LAB counts and should not be interpreted as probiotic counts.

Table 3: Selected Curd-Derived Undefined Mixed Starter Culture Concentrations and Corresponding Fermentation Characteristics.

Beverage	Starter (% v/v)	Time (h)	pH	TA (% LA)	TSS (°Brix)	Presumptive LAB (CFU/mL)
White rice–almond	5	7.5	4.38 ± 0.022	0.88 ± 0.231	9.79 ± 0.014	4.2×10^9 ± 0.121
Red rice–almond	4	6.5	4.49 ± 0.042	0.79 ± 0.074	9.83 ± 0.055	2.8×10^9 ± 0.212

Beverage	Starter (% v/v)	Time (h)	pH	TA (% LA)	TSS (°Brix)	Presumptive LAB (CFU/ mL)
Finger millet–oat	5	6.0	4.50 ± 0.018	0.74 ± 0.113	11.10 ± 0.036	1.2×10^{10} ± 0.178
Pearl millet–oat	4	8.5	4.56 ± 0.014	0.78 ± 0.112	10.66 ± 0.039	7.6×10^{9} ± 0.164
Sorghum–oat	4	6.0	4.55 ± 0.012	0.74 ± 0.011	10.94 ± 0.036	8.9×10^{9} ± 0.111
Barley–oat	5	7.0	4.46 ± 0.012	0.82 ± 0.016	9.62 ± 0.038	3.8×10^{9} ± 0.153

3.3 Proximate composition and energy value of cereal raw materials

The proximate composition and energy values of the cereal raw materials used for beverage formulation are presented in Table 4. Moisture content ranged from 9.76 ± 0.03% in pearl millet to 11.70 ± 0.065% in red rice. Fat content was lowest in white rice (0.50 ± 0.023%) and highest in pearl millet (2.82 ± 0.04%), whereas protein ranged from 7.70 ± 0.013% in white rice to 12.01 ± 0.050% in barley.

Total dietary fibre showed marked variation among the cereals. Pearl millet contained the highest reported value (10.76 ± 0.037%), followed by finger millet (10.30 ± 0.025%), barley (10.20 ± 0.045%), and sorghum (9.56 ± 0.018%), while substantially lower values were observed in red rice (3.03 ± 0.031%) and white rice (1.82 ± 0.25%). Available carbohydrate by difference as 100 − [moisture + fat + protein + ash + total dietary fibre], ranged from 64.33 ± 0.094% in barley to 78.38 ± 0.253% in white rice. The values for red rice, finger millet, pearl millet, and sorghum were 74.73 ± 0.078%, 66.37 ± 0.067%, 65.61 ± 0.083%, and 66.82 ± 0.327%, respectively. Energy values were recalculated using the Atwater factors [4 kcal/g for protein, 4 kcal/g for available carbohydrate by difference, and 9 kcal/g for fat] and converted to kJ using 1 kcal = 4.184 kJ. The recalculated energy values ranged from 1326.58 ± 2.15 kJ/100 g in barley to 1459.46 ± 4.33 kJ/100 g in white rice. These compositional differences provide an important nutritional basis for interpreting matrix-dependent differences observed during fermentation and in the finished beverages.

Table 4: Proximate Composition and Energy Value of Cereal Raw Materials.

Raw material	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	Total dietary fibre (%)	Available carbohydrate by difference (%)	Energy (kJ/100 g)
White rice	11.08 ± 0.012	0.50 ± 0.023	7.70 ± 0.013	0.52 ± 0.023	1.82 ± 0.25	78.38 ± 0.253	1459.46 ± 4.33
Red rice	11.70 ± 0.065	1.32 ± 0.026	7.88 ± 0.008	1.34 ± 0.015	3.03 ± 0.031	74.73 ± 0.078	1432.27 ± 1.64
Finger millet	10.98 ± 0.034	1.86 ± 0.030	9.30 ± 0.030	1.19 ± 0.031	10.30 ± 0.025	66.37 ± 0.067	1336.45 ± 1.67
Pearl millet	9.76 ± 0.030	2.82 ± 0.040	9.36 ± 0.040	1.69 ± 0.037	10.76 ± 0.037	65.61 ± 0.083	1360.89 ± 2.16
Sorghum	9.87 ± 0.040	2.23 ± 0.023	10.31 ± 0.090	1.21 ± 0.310	9.56 ± 0.018	66.82 ± 0.327	1374.82 ± 5.74
Barley	10.35 ± 0.050	1.30 ± 0.032	12.01 ± 0.050	1.81 ± 0.027	10.20 ± 0.045	64.33 ± 0.094	1326.58 ± 2.15

3.4 Physicochemical characteristics of standardized beverages

The physicochemical characteristics observed in the present study are generally consistent with those reported for fermented cereal- and millet-based beverages. The final pH values of the developed beverages (4.45–4.56) indicate effective acidification of the

cereal matrices during fermentation. Gupta and Gaur [31] reported final pH values of approximately 4.06–4.64 for fermented beverages prepared from different millet varieties, demonstrating that the extent of acidification is strongly influenced by the cereal substrate. Similarly, Kitessa (2024) reported that fermentation of cereal-based foods and beverages generally results in a reduction in pH and an increase in acidity due to the production of organic acids by fermentative microorganisms. These observations are comparable with the present study, in which pH values of 4.45–4.56 were accompanied by titratable acidity values of 0.741–0.811% lactic acid.

Differences in TSS among the developed beverages may be attributed to variations in the carbohydrate composition of the cereal and plant-milk matrices and to the extent of carbohydrate transformation during fermentation. Fermentation can modify soluble carbohydrate concentrations through the combined effects of enzymatic starch hydrolysis and microbial utilization of fermentable sugars. Udeh et al. [32], while studying fermented finger millet and sorghum malt beverages, also demonstrated that fermentation time influenced sugar content and other physicochemical characteristics, indicating that changes in soluble solids are dependent on both substrate characteristics and fermentation conditions.

The viscosity of the beverages in the present study ranged from 27.70 to 35.24 cP, with the highest value recorded for the finger millet beverage. Differences in viscosity among cereal-based beverages may arise from variations in starch composition, dietary fibre, suspended solids, water-binding capacity, and fermentation-induced structural changes. A fermented finger millet-based beverage developed using lactic acid bacterial cultures showed increased apparent viscosity associated with microbial exopolysaccharide production, demonstrating that both the cereal matrix and microbial activity can contribute to the rheological characteristics of fermented beverages. In contrast, Udeh et al. [32] observed fermentation-dependent decreases in viscosity in some finger millet beverages, illustrating that the direction and magnitude of viscosity changes depend on the cereal substrate, starter culture, and processing conditions.

Overall, comparison with previous studies indicates that the physicochemical characteristics of fermented cereal-based beverages are strongly matrix- and process-dependent. The relatively narrow acidic pH range observed in the present formulations, together with differences in TSS and viscosity, is therefore consistent with the variable physicochemical behaviour previously reported for fermented millet and other cereal-based beverage systems.

Table 5: Physicochemical Characteristics of the Standardized Fermented Beverages.

Finished product	pH	Titratable acidity (% LA)	TSS (°Brix)	Viscosity (cP)
White rice beverage	4.45 ± 0.009	0.811 ± 0.102	9.79 ± 0.121	28.35 ± 0.035
Red rice beverage	4.49 ± 0.020	0.780 ± 0.028	9.84 ± 0.282	28.97 ± 0.066
Finger millet beverage	4.52 ± 0.038	0.748 ± 0.042	11.69 ± 0.188	35.24 ± 0.172
Sorghum beverage	4.55 ± 0.005	0.755 ± 0.061	11.08 ± 0.098	33.20 ± 0.120
Pearl millet beverage	4.56 ± 0.078	0.772 ± 0.036	10.59 ± 0.077	34.01 ± 0.066
Barley beverage	4.52 ± 0.014	0.741 ± 0.028	9.89 ± 0.062	27.70 ± 0.075

3.5 Proximate composition of standardized beverages

The proximate composition of the standardized fermented cereal-based beverages is presented in Table 6. Considerable numerical variation was observed among the formulations, reflecting differences in the cereal and plant-milk components used in beverage preparation. Moisture was the predominant component in all formulations and ranged from 81.33 ± 0.025% to 89.15 ± 0.019%. The white rice beverage showed the highest moisture content (89.15 ± 0.019%), followed by the red rice beverage (87.63 ± 0.082%), whereas the pearl millet beverage showed the lowest value (81.33 ± 0.025%). The comparatively lower moisture contents of the millet- and barley-based beverages corresponded with their generally greater contribution of total solids.

Fat content ranged from 1.20 ± 0.061% in the finger millet beverage to 1.70 ± 0.068% in the barley beverage. Pearl millet (1.69 ± 0.076%) and sorghum (1.51 ± 0.067%) beverages also showed relatively higher fat contents, while the white rice beverage contained 1.26

± 0.045%. These differences may reflect the intrinsic lipid composition of the cereal ingredients as well as the contribution of the plant-milk components incorporated into the respective formulations. Protein content ranged from 0.32 ± 0.055% to 2.06 ± 0.028%. The highest numerical protein content was recorded in the sorghum beverage (2.06 ± 0.028%), followed by the red rice (1.98 ± 0.024%), pearl millet (1.76 ± 0.019%), and white rice (1.73 ± 0.027%) beverages. The markedly lower protein value recorded for the barley beverage (0.32 ± 0.055%) should be interpreted cautiously and verified against the primary analytical records because it is substantially lower than the values obtained for the other formulations.

Ash content ranged from 0.72 ± 0.003% in the white rice beverage to 1.59 ± 0.002% in the finger millet beverage. The sorghum (1.55 ± 0.044%), pearl millet (1.49 ± 0.088%), and barley (1.35 ± 0.076%) beverages also showed comparatively higher ash contents than the rice-based beverages. This pattern may be associated with differences in the mineral-containing fractions of the cereal ingredients and other formulation components. Total dietary fibre varied considerably among the beverages. The sorghum beverage showed the highest numerical value (4.27 ± 0.071%), closely followed by the finger millet beverage (4.25 ± 0.044%). Pearl millet contained 2.73 ± 0.034%, while barley, white rice, and red rice beverages contained 1.96 ± 0.099%, 1.67 ± 0.022%, and 1.56 ± 0.117%, respectively. The comparatively greater dietary fibre content of the millet-based formulations is consistent with their greater contribution of fibre-rich cereal fractions. Differences among formulations may also reflect the type of cereal, degree of processing, germination treatment, and formulation composition.

Total sugar content ranged from 1.30 ± 0.076% in the red rice beverage to 2.98 ± 0.021% in the finger millet beverage. The finger millet beverage showed the highest numerical total sugar content, followed by pearl millet (2.34 ± 0.021%) and sorghum (2.19 ± 0.023%). Differences in total sugar content may be associated with the initial carbohydrate composition of the cereal matrices and the formation and utilization of soluble sugars during cereal processing and fermentation.

Available carbohydrate by difference ranged from 5.47 ± 0.079% in the white rice beverage to 11.00 ± 0.037% in the pearl millet beverage. The barley beverage also showed a relatively high carbohydrate content (10.64 ± 0.129%), followed by finger millet (9.83 ± 0.026%) and sorghum (8.48 ± 0.089%). The higher available-carbohydrate values of the millet- and barley-based formulations are consistent with their lower moisture contents and greater total solids compared with the rice-based beverages.

Overall, the proximate composition demonstrated that the nutritional composition of the standardized fermented beverages was strongly influenced by the cereal and plant-milk matrix. The millet-based beverages generally provided greater total dietary fibre and ash contents, whereas the rice-based beverages were characterized by higher moisture and lower total solids. Such compositional differences may also contribute to the variations observed in TSS, viscosity, fermentation behaviour, and sensory characteristics among the developed beverages.

Table 6: Proximate Composition of Standardized Fermented Beverages (%).

Product	Moisture	Fat	Protein	Ash	Dietary Fibre	Total sugar	Available carbohydrate by difference (%)
White rice beverage	89.15 ± 0.019	1.26 ± 0.045	1.73 ± 0.027	0.72 ± 0.003	1.67 ± 0.022	1.43 ± 0.019	5.47 ± 0.079
Red rice beverage	87.63 ± 0.082	1.48 ± 0.100	1.98 ± 0.024	0.95 ± 0.049	1.56 ± 0.117	1.30 ± 0.076	6.40 ± 0.209
Finger millet beverage	81.78 ± 0.088	1.20 ± 0.061	1.35 ± 0.132	1.59 ± 0.002	4.25 ± 0.044	2.98 ± 0.021	9.83 ± 0.026
Sorghum beverage	82.13 ± 0.118	1.51 ± 0.067	2.06 ± 0.028	1.55 ± 0.044	4.27 ± 0.071	2.19 ± 0.023	8.48 ± 0.089
Pearl millet beverage	81.33 ± 0.025	1.69 ± 0.076	1.76 ± 0.019	1.49 ± 0.088	2.73 ± 0.034	2.34 ± 0.021	11.00 ± 0.037
Barley beverage	84.03 ± 0.018	1.70 ± 0.068	0.32 ± 0.055	1.35 ± 0.076	1.96 ± 0.099	1.86 ± 0.049	10.64 ± 0.129

3.6 Microbial load of cereal- and millet-based fermented beverages

The microbiological characteristics of the standardized fermented cereal-based beverages are presented in Table 7. Coliforms were not detected in any of the formulations under the analytical conditions used. This finding indicates satisfactory hygienic quality with respect to the coliform indicator; however, the absence of detectable coliforms alone should not be interpreted as evidence of comprehensive microbiological safety because a complete foodborne-pathogen assessment was not performed.

The total plate count varied among the beverage formulations, ranging numerically from 3.0 × 10^9 CFU/mL in the barley beverage to 7.3 × 10^9 CFU/mL in the red rice beverage. The red rice beverage showed the highest numerical total plate count, followed by the sorghum (6.6 × 10^9 CFU/mL) and white rice (6.1 × 10^9 CFU/mL) beverages. Finger millet and pearl millet beverages showed total plate counts of 4.7 × 10^9 and 4.3 × 10^9 CFU/mL, respectively, while the barley beverage showed the lowest numerical count. The variation among formulations may reflect differences in nutrient availability, fermentable substrates, and other physicochemical characteristics of the cereal and plant-milk matrices that influence microbial growth during fermentation.

Presumptive LAB counts also varied among the beverage formulations. The finger millet beverage showed the highest numerical LAB population (10.6 × 10^9 CFU/mL), followed by the pearl millet (7.8 × 10^9 CFU/mL), red rice (6.4 × 10^9 CFU/mL), barley (6.3 × 10^9 CFU/mL), and white rice (4.2 × 10^9 CFU/mL) beverages. The sorghum beverage showed the lowest numerical presumptive LAB count (3.1 × 10^9 CFU/mL). The comparatively high LAB population observed in the finger millet beverage suggests that this cereal matrix provided favourable conditions for growth and/or persistence of the fermentative microbial population. Differences in carbohydrate availability, nutrient composition, buffering capacity, and other matrix-specific characteristics may have contributed to the observed variation in LAB counts.

The occurrence of high presumptive LAB populations across the formulations confirms the establishment of an active fermentative microbial population under the conditions employed. Nevertheless, these viable counts should not be interpreted as evidence of probiotic functionality. The curd-derived undefined mixed starter culture consisted of an undefined mixed microbial population, and species- and strain-level identification, characterization, and demonstration of specific health benefits were not performed. Therefore, the microbial populations recovered on MRS agar are appropriately reported as presumptive LAB counts rather than probiotic counts.

Table 7: Microbial Analysis of Standardized Fermented Beverages

Finished product	Coliform	Total plate count	Presumptive LAB count
		CFU/mL	CFU/mL
White rice beverage	ND	6.1 × 10^9 ± 0.079	4.2 × 10^9 ± 0.082

Finished product	Coliform	Total plate count	Presumptive LAB count
Red rice beverage	ND	$7.3 \times 10^9 \pm 0.131$	$6.4 \times 10^9 \pm 0.220$
Finger millet beverage	ND	$4.7 \times 10^9 \pm 0.031$	$10.6 \times 10^9 \pm 0.072$
Sorghum beverage	ND	$6.6 \times 10^9 \pm 0.072$	$3.1 \times 10^9 \pm 0.018$
Pearl millet beverage	ND	$4.3 \times 10^9 \pm 0.086$	$7.8 \times 10^9 \pm 0.049$
Barley beverage	ND	$3.0 \times 10^9 \pm 0.119$	$6.3 \times 10^9 \pm 0.052$

3.7 Sensory evaluation and selection of curd-derived undefined mixed starter culture concentration

The effect of curd-derived undefined mixed starter culture concentration on the sensory characteristics of the six cereal-based beverage formulations was evaluated using colour, flavour, taste, texture, and overall acceptability as the principal sensory attributes. Starter concentrations ranging from 1% to 5% were evaluated, and clear formulation-dependent differences were observed in the sensory response. In general, sensory scores increased as the starter concentration increased; however, the concentration associated with the highest numerical acceptability differed among the cereal matrices. This indicates that a single starter concentration was not equally suitable for all formulations and supports the independent selection of starter level for each beverage.

For the white rice–almond beverage, sensory scores increased progressively from 1% to 5% starter culture. Overall acceptability increased from 7.79 ± 0.200 at 1% to 8.20 ± 0.180, 8.52 ± 0.160, 8.81 ± 0.140, and 8.96 ± 0.110 at 2%, 3%, 4%, and 5%, respectively. At 5%, the beverage also recorded its highest numerical scores for colour (8.90 ± 0.130), flavour (8.98 ± 0.120), taste (9.00 ± 0.100), and texture (8.96 ± 0.110). Consequently, 5% curd-derived undefined mixed starter culture was selected for the white rice formulation. A different response was observed for the red rice–almond beverage. Sensory scores increased from 1% to 4%, followed by a slight decline at 5%. Overall acceptability increased from 7.74 ± 0.271 at 1% to 8.12 ± 0.184 at 2%, 8.49 ± 0.161 at 3%, and reached its highest numerical value of 8.95 ± 0.116 at 4%. At this concentration, colour, flavour, taste, and texture scores were 8.90 ± 0.130, 8.96 ± 0.127, 9.00 ± 0.109, and 8.94 ± 0.114, respectively. Increasing the starter concentration to 5% reduced overall acceptability to 8.75 ± 0.149. Therefore, 4% curd-derived undefined mixed starter culture was selected for the red rice formulation.

For the barley beverage, sensory acceptability increased progressively with starter concentration. Overall acceptability increased from 7.71 ± 0.217 at 1% to 8.07 ± 0.182 at 2%, 8.44 ± 0.160 at 3%, 8.76 ± 0.133 at 4%, and reached 9.00 ± 0.110 at 5%. The 5% formulation also recorded the highest numerical scores for colour (8.94 ± 0.118), flavour (9.00 ± 0.112), taste (9.04 ± 0.104), and texture (9.02 ± 0.108). Based on the combined sensory response, 5% curd-derived undefined mixed starter culture was selected for the barley formulation. A similar progressive improvement was observed in the finger millet beverage. Overall acceptability increased from 7.15 ± 0.184 at 1% starter culture to 7.82 ± 0.157, 8.38 ± 0.136, and 8.91 ± 0.110 at 2%, 3%, and 4%, respectively, before reaching the highest value of 9.27 ± 0.080 at 5%. At the selected 5% concentration, colour, flavour, taste, and texture scores were 9.20 ± 0.086, 9.28 ± 0.079, 9.34 ± 0.074, and 9.26 ± 0.081, respectively. Thus, 5% curd-derived undefined mixed starter culture was selected for the finger millet formulation.

For the pearl millet beverage, all sensory attributes showed a progressive numerical increase between 1% and 5% starter culture. Overall acceptability increased from 7.12 ± 0.188 at 1% to 7.83 ± 0.160 at 2%, 8.48 ± 0.137 at 3%, 9.16 ± 0.082 at 4%, and reached the highest numerical value of 9.35 ± 0.074 at 5%. The 5% formulation recorded colour, flavour, taste, and texture scores of 9.26 ± 0.081, 9.34 ± 0.075, 9.42 ± 0.069, and 9.36 ± 0.073, respectively. Although 5% gave the highest numerical sensory score, the standardized pearl millet formulation retained 4% starter culture because final starter selection was based on the combined fermentation response (fermentation time, pH, titratable acidity, TSS, presumptive LAB count, and sensory acceptability) rather than sensory score alone. In contrast, the sorghum beverage showed an increase in sensory acceptability only up to 4% starter culture, followed by a reduction at 5%. Overall acceptability increased from 7.25 ± 0.180 at 1% to 7.98 ± 0.151 at 2% and 8.64 ± 0.129 at 3%, reaching the highest numerical value of 9.40 ± 0.071 at 4%. The

corresponding scores for colour, flavour, taste, and texture were 9.30 ± 0.078, 9.40 ± 0.072, 9.48 ± 0.067, and 9.42 ± 0.070, respectively. At 5%, overall acceptability declined to 8.92 ± 0.107, together with reductions in the other sensory attributes. Therefore, 4% curd-derived undefined mixed starter culture was selected for the sorghum formulation.

A 5% starter concentration produced the highest numerical overall acceptability in the white rice, barley, finger millet, and pearl millet sensory trials, whereas 4% produced the highest numerical acceptability in the red rice and sorghum trials. Final starter selection, however, was based on the combined physicochemical, microbiological, fermentation-time, and sensory response. Accordingly, the standardized pearl millet formulation retained 4% starter despite the higher numerical sensory score at 5%. This matrix-dependent response is scientifically plausible because cereal matrices differ in carbohydrate, protein, fibre, phenolic, mineral, and buffering characteristics, which can influence microbial metabolism and sensory changes during fermentation.

Fermentation can improve the sensory properties of cereal-based beverages through several interacting mechanisms. Fermentative microorganisms utilize available carbohydrates and generate organic acids as well as volatile and non-volatile metabolites that influence aroma and taste. Microbial and enzymatic transformations of proteins and carbohydrates may additionally generate flavour precursors and modify the physical structure of the beverage, thereby affecting texture and mouthfeel. Reviews of fermented cereal beverages similarly indicate that LAB-mediated fermentation can modify flavour and rheological properties and that the final sensory response depends strongly on the combination of cereal substrate, microbial culture, and fermentation conditions [33,8,12].

The lower sensory scores observed at 5% starter culture in the red rice and sorghum formulations may indicate that fermentation beyond the preferred level altered the balance of taste, aroma, acidity, or other sensory characteristics. Greater inoculum levels can potentially accelerate substrate utilization and metabolite production; however, excessive acidification cannot be stated as the confirmed cause of the decline in the present study unless acidity was measured for these exact sensory treatments. Therefore, the decrease at 5% is more appropriately interpreted as evidence that the sensory profile produced at this concentration was less favourably evaluated by the trained panel. Studies on fermented cereal beverages have similarly demonstrated that acceptability depends on the microbial culture and the physicochemical and flavour characteristics generated during fermentation.

Considering the complete standardization criteria, 5% curd-derived undefined mixed starter culture was selected for the white rice, barley, and finger millet beverages, whereas 4% was selected for the red rice, pearl millet, and sorghum beverages. For pearl millet, the 5% treatment produced the highest numerical sensory score, but 4% was retained in the standardized formulation on the basis of the combined fermentation response rather than sensory acceptability alone. These selected concentrations were used for subsequent evaluation of the standardized fermented cereal-based beverages.

The sensory response patterns across starter-culture concentrations for the six standardized beverage formulations are illustrated in Figure 1 (a–f).

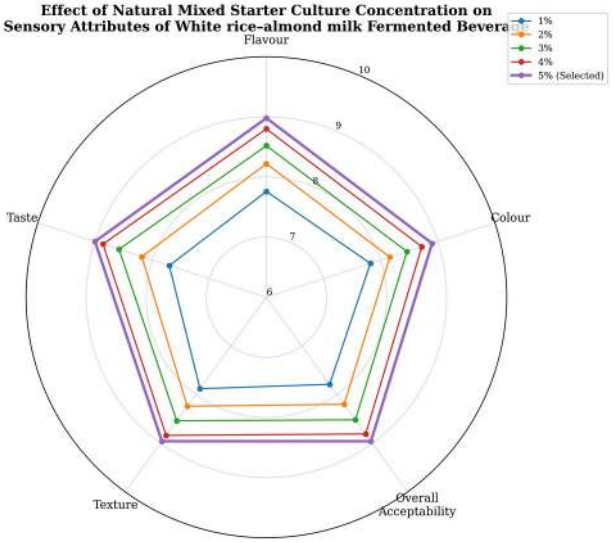

Figure 1: (A). Effect of Curd-Derived Undefined Mixed Starter Culture Concentration on the Sensory Attributes of the White Rice–Almond Milk Fermented Beverage.

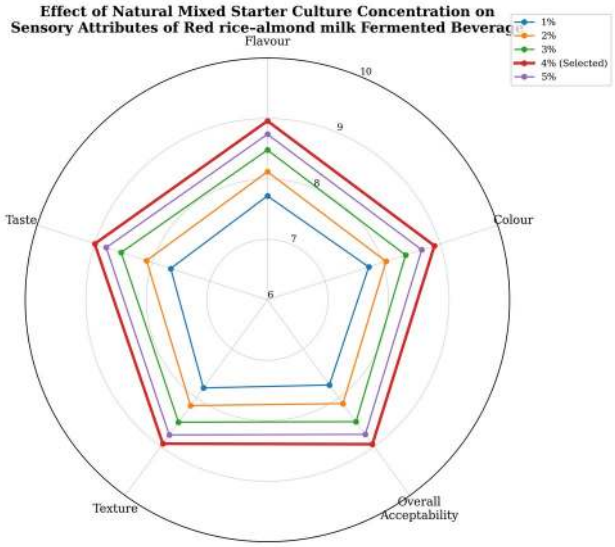

Figure 1: (B). Effect of Curd-Derived Undefined Mixed Starter Culture Concentration on the Sensory Attributes of the Red Rice–Almond Milk Fermented Beverage.

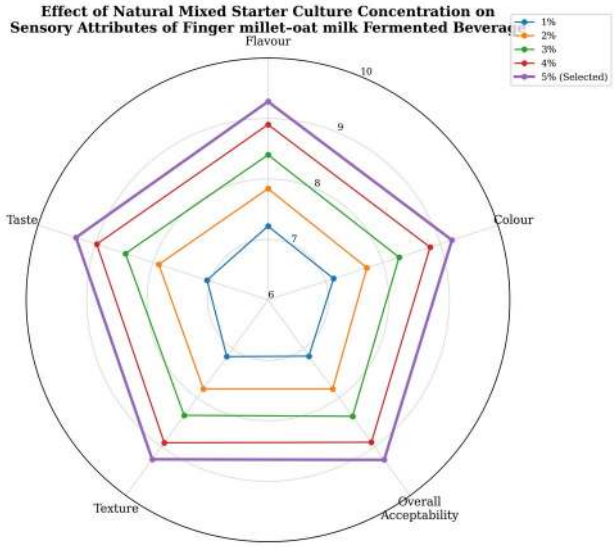

Figure 1: (D). Effect of Curd-Derived Undefined Mixed Starter Culture Concentration on the Sensory Attributes of the Finger Millet–Oat Milk Fermented Beverage.

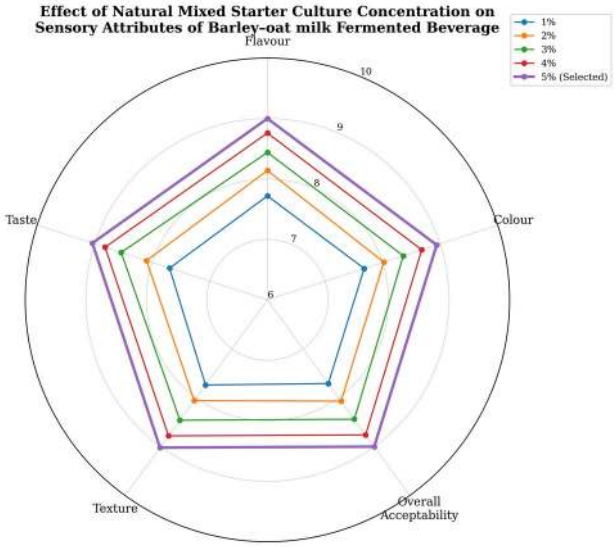

Figure 1: (C). Effect of Curd-Derived Undefined Mixed Starter Culture Concentration on the Sensory Attributes of the Barley–Oat Milk Fermented Beverage.

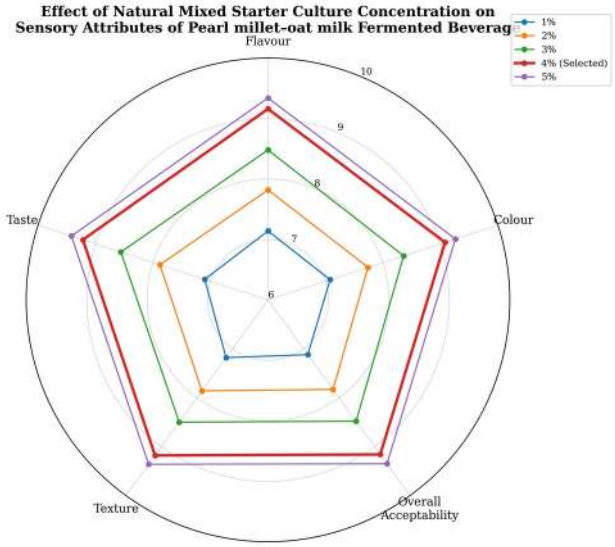

Figure 1: (E). Effect of Curd-Derived Undefined Mixed Starter Culture Concentration on the Sensory Attributes of the Pearl Millet–Oat Milk Fermented Beverage.

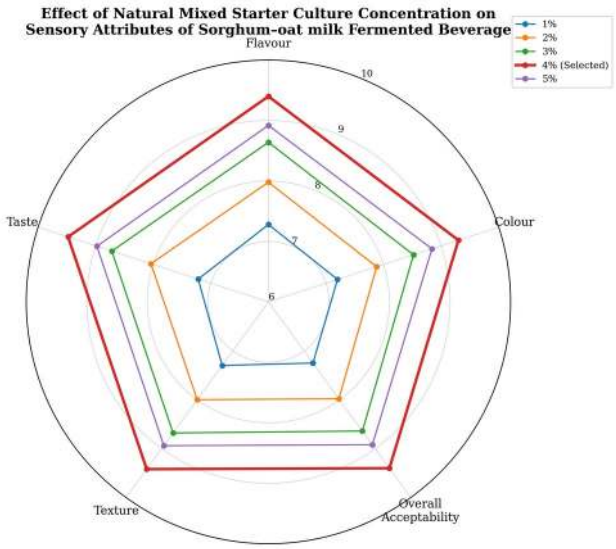

Figure 1: (F). Effect of Curd-Derived Undefined Mixed Starter Culture Concentration on the Sensory Attributes of the Sorghum–Oat Milk Fermented Beverage.

3.8 Effect of storage temperature on physicochemical and microbiological stability

The physicochemical and microbiological characteristics of the fermented cereal-based beverages showed time-dependent changes during storage. Under refrigerated conditions (4 ± 2 °C), changes were observed gradually over 21 days, whereas larger numerical changes were observed during 7 days of ambient storage (25 ± 2 °C). The following results are therefore presented as observed temporal trends across the three independently prepared batches; they should not be interpreted as inferential evidence from a repeated-measures or mixed-effects model.

pH. The pH of all beverage formulations decreased progressively during storage (Table 8). Under refrigerated conditions, the initial pH ranged from 4.39 ± 0.030 to 4.56 ± 0.030 and decreased to 4.03 ± 0.004–4.29 ± 0.015 after 21 days. Finger millet showed the lowest final pH (4.03 ± 0.004), whereas pearl millet retained the highest value (4.29 ± 0.015). In comparison, acidification proceeded considerably faster at ambient temperature. Initial pH values of 4.39 ± 0.099 –4.56 ± 0.089 declined to 2.78 ± 0.070–3.28 ± 0.095 within 7 days, with finger millet showing the lowest final pH. The decrease in pH can be attributed to continued microbial metabolism of available fermentable carbohydrates and accumulation of organic acids during post-fermentation. The greater decline under ambient conditions indicates that higher storage temperature favoured continued metabolic activity, whereas refrigeration slowed the acidification process. Similar decreases in pH during cereal fermentation and storage have been associated with organic acid production by LAB and are strongly influenced by cereal composition, fermentable carbohydrate availability, and buffering capacity [8,12].

Titratable acidity. The increase in titratable acidity corresponded with the progressive reduction in pH (Table 9). During refrigerated storage, acidity increased from an initial range of 0.689 ± 0.131–0.778 ± 0.021% lactic acid to 0.755 ± 0.008–0.925 ± 0.019% after 21 days. White rice exhibited the highest numerical final acidity (0.925 ± 0.019%), followed by barley (0.840 ± 0.087%) and sorghum (0.813 ± 0.052%). At ambient temperature, the increase occurred more rapidly, with acidity reaching 0.855 ± 0.068–0.929 ± 0.107% within 7 days. White rice and finger millet showed the highest numerical final acidity values. The inverse relationship between pH and titratable acidity supports continued production and accumulation of organic acids during storage. Comparable increases in acidity have been reported in fermented cereal beverages and are associated with the conversion of fermentable substrates into lactic acid and other fermentation metabolites by LAB [8,12]. The more rapid increase under ambient conditions further demonstrates the importance of refrigeration in limiting post-fermentation acid development.

Total soluble solids. Total soluble solids decreased in all formulations during storage (Table 10). Under refrigeration, initial TSS values ranged from 9.89 ± 0.031 to 11.69 ± 0.221 °Brix and decreased to 8.25 ± 0.007–10.35 ± 0.050 °Brix after 21 days. Finger millet retained the highest final TSS (10.35 ± 0.050 °Brix), whereas white rice showed the lowest value (8.25 ± 0.007 °Brix). A more rapid decline was observed at ambient temperature, where TSS decreased to 8.19 ± 0.097–10.15 ± 0.028 °Brix by day 7. The decrease in TSS may be associated with microbial utilization of soluble sugars and other fermentable substrates for growth and organic acid production. However, cereal fermentation involves simultaneous carbohydrate hydrolysis and microbial utilization; therefore, the observed TSS values represent the net effect of several biochemical processes rather than sugar utilization alone. Changes in soluble carbohydrates during fermentation have similarly been reported for cereal- and millet-based beverages [8,12].

Viscosity. Storage temperature produced contrasting effects on beverage viscosity (Table 11). Under refrigerated conditions, viscosity generally increased during storage, with values increasing from an initial range of 27.70 ± 0.087–35.24 ± 0.011 cP to 29.75 ± 0.060–36.84 ± 0.030 cP after 21 days. Finger millet exhibited the highest viscosity throughout refrigerated storage, reaching 36.84 ± 0.030 cP on day 21, whereas barley showed the lowest final viscosity (29.75 ± 0.060 cP). The increase may be related to continued hydration and swelling of starch and dietary fibre, water redistribution, and interactions among starch, protein, and other suspended components of the cereal matrix. Although microbial exopolysaccharide production can also contribute to increased viscosity in fermented cereal systems, this mechanism cannot be confirmed in the present study because exopolysaccharides were not directly measured.

In contrast, viscosity generally decreased during ambient storage. By day 7, viscosity ranged from 26.38 ± 0.066 cP in barley to 35.55 ± 0.029 cP in finger millet. Reductions were particularly evident in barley, pearl millet, sorghum, white rice, and red rice beverages. The decrease may reflect continued biochemical modification of starch and other polysaccharides under conditions of greater microbial activity and acidification. Acid-mediated and enzymatic degradation of complex carbohydrates can weaken the structural network of cereal beverages and consequently alter their rheological characteristics. The different viscosity responses under refrigerated and ambient conditions therefore suggest that the balance between hydration and structural reorganization on one hand, and carbohydrate degradation on the other, was strongly influenced by storage temperature.

Presumptive LAB viability. Presumptive LAB counts declined progressively under both storage conditions (Table 12), but the reduction was considerably slower under refrigeration. Initial counts ranged from 3.1×10^9 to 10.6×10^9 CFU/mL, with finger millet showing the highest initial population. After 21 days of refrigerated storage, the counts remained between 5.2×10^6 and 2.7×10^7 CFU/mL. White rice retained the highest numerical population at day 21 (2.7×10^7 CFU/mL), followed by finger millet (1.2×10^7 CFU/mL), while the remaining formulations retained counts in the order of 10^6 CFU/mL. Thus, although LAB viability decreased during refrigerated storage, viable populations persisted throughout the 21-day observation period. The decline may be related to increasing acidity, depletion of available nutrients, accumulation of fermentation metabolites, and other environmental stresses encountered during prolonged storage. Matrix-dependent differences in LAB survival during storage have also been reported for cereal and plant-based fermented beverages [8,34].

At ambient temperature, presumptive LAB viability declined much more rapidly. By day 5, counts had decreased to approximately 3.0×10^6–5.5×10^7 CFU/mL, and by day 7 all formulations contained fewer than 1×10^6 CFU/mL, with final counts ranging from 3.9×10^5 to 9.9×10^5 CFU/mL. The accelerated decline at 25 ± 2 °C may be attributed to faster metabolic activity followed by nutrient depletion, greater accumulation of acidic metabolites, and increased environmental stress. In contrast, refrigeration reduced the rate of these processes and consequently supported longer persistence of viable LAB. The observed temperature-dependent loss of viability is consistent with previous reports demonstrating that storage conditions and beverage matrix composition are important determinants of LAB survival in fermented cereal-based products [8,34].

Yeasts and moulds. Yeast and mould populations were monitored during storage using PDA as described in Section 2.5. No yeast or mould colonies were detected (ND) in the analysed beverage samples at the evaluated storage intervals under the stated analytical conditions. These findings indicate absence of detectable fungal growth within the analytical detection conditions used; however, they should not be interpreted as a complete spoilage or safety validation.

Overall, the observed storage trends indicated greater physicochemical and microbiological stability under refrigeration than under ambient storage. Refrigerated samples showed slower numerical decreases in pH and TSS, smaller increases in titratable acidity, comparatively limited changes in viscosity, and higher presumptive LAB populations over the evaluated period. Ambient samples showed more rapid numerical changes in these parameters. These findings support refrigerated storage for maintaining the measured quality characteristics under the conditions of this study. Nevertheless, the present results represent a storage-stability assessment and should not be interpreted as validation of commercial shelf life without

additional pathogen, spoilage, packaging, and sensory validation.

Because the curd-derived undefined mixed starter culture used in this study consisted of an undefined mixed microbial population and species- or strain-level identification was not performed, viable counts obtained on MRS agar are appropriately described as presumptive LAB counts rather than probiotic counts. Similarly, retention of counts above 10^6 CFU/mL during refrigerated storage should be interpreted only as persistence of viable presumptive LAB and not as evidence of probiotic functionality or health benefits.

Table 8: Changes in pH During Refrigerated and Ambient Storage

Beverage	Refrig. Day 0	Day 7	Day 14	Day 21	Ambient Day 0	Day 3	Day 5	Day 7
White rice	4.51 ± 0.018	4.50 ± 0.009	4.35 ± 0.040	4.24 ± 0.065	4.51 ± 0.032	4.29 ± 0.089	4.01 ± 0.047	3.28 ± 0.095
Red rice	4.49 ± 0.030	4.45 ± 0.018	4.43 ± 0.037	4.27 ± 0.030	4.49 ± 0.037	4.15 ± 0.022	3.87 ± 0.007	3.20 ± 0.031
Finger millet	4.39 ± 0.030	4.32 ± 0.006	4.29 ± 0.029	4.03 ± 0.004	4.39 ± 0.099	3.92 ± 0.036	3.19 ± 0.029	2.78 ± 0.070
Pearl millet	4.44 ± 0.030	4.42 ± 0.023	4.38 ± 0.035	4.29 ± 0.015	4.44 ± 0.013	4.08 ± 0.003	3.68 ± 0.039	3.09 ± 0.095
Sorghum	4.56 ± 0.030	4.50 ± 0.018	4.45 ± 0.039	4.25 ± 0.022	4.56 ± 0.089	4.11 ± 0.029	3.77 ± 0.069	3.20 ± 0.009
Barley	4.52 ± 0.030	4.49 ± 0.033	4.42 ± 0.073	4.19 ± 0.011	4.52 ± 0.041	4.02 ± 0.039	3.55 ± 0.013	2.89 ± 0.016

Table 9: Changes in Titratable Acidity (% Lactic Acid) During Refrigerated and Ambient Storage

Beverage	Refrig. Day 0	Day 7	Day 14	Day 21	Ambient Day 0	Day 3	Day 5	Day 7
White rice	0.778 ± 0.021	0.791 ± 0.032	0.889 ± 0.045	0.925 ± 0.019	0.728 ± 0.103	0.790 ± 0.012	0.867 ± 0.101	0.929 ± 0.099
Red rice	0.700 ± 0.105	0.712 ± 0.022	0.730 ± 0.031	0.755 ± 0.008	0.700 ± 0.077	0.742 ± 0.038	0.798 ± 0.191	0.855 ± 0.068
Finger millet	0.708 ± 0.029	0.719 ± 0.061	0.735 ± 0.039	0.771 ± 0.077	0.708 ± 0.118	0.780 ± 0.138	0.893 ± 0.099	0.929 ± 0.107
Pearl millet	0.689 ± 0.131	0.700 ± 0.020	0.734 ± 0.008	0.759 ± 0.019	0.699 ± 0.065	0.735 ± 0.008	0.798 ± 0.018	0.892 ± 0.056
Sorghum	0.699 ± 0.201	0.755 ± 0.028	0.782 ± 0.011	0.813 ± 0.052	0.729 ± 0.055	0.795 ± 0.028	0.892 ± 0.041	0.921 ± 0.150
Barley	0.736 ± 0.087	0.785 ± 0.010	0.799 ± 0.029	0.840 ± 0.087	0.736 ± 0.035	0.745 ± 0.110	0.799 ± 0.090	0.911 ± 0.067

Table 10: Changes in Total Soluble Solids (°Brix) During Refrigerated and Ambient Storage

Beverage	Refrig. Day 0	Day 7	Day 14	Day 21	Ambient Day 0	Day 3	Day 5	Day 7
White rice	10.09 ± 0.022	9.32 ± 0.003	9.05 ± 0.018	8.25 ± 0.007	10.09 ± 0.027	9.83 ± 0.013	9.37 ± 0.068	8.19 ± 0.097
Red rice	10.94 ± 0.014	10.63 ± 0.016	10.10 ± 0.007	9.78 ± 0.016	9.94 ± 0.017	9.50 ± 0.056	9.17 ± 0.017	8.82 ± 0.056
Finger millet	11.69 ± 0.221	11.34 ± 0.033	10.85 ± 0.011	10.35 ± 0.050	11.39 ± 0.032	11.05 ± 0.023	10.33 ± 0.091	9.32 ± 0.050
Pearl millet	11.08 ± 0.052	10.79 ± 0.004	10.25 ± 0.039	9.95 ± 0.016	11.28 ± 0.045	11.00 ± 0.034	10.85 ± 0.009	10.05 ± 0.016
Sorghum	10.95 ± 0.035	10.69 ± 0.007	10.15 ± 0.053	9.89 ± 0.028	11.01 ± 0.019	10.88 ± 0.087	10.42 ± 0.050	10.15 ± 0.028
Barley	9.89 ± 0.031	9.37 ± 0.040	9.00 ± 0.038	8.65 ± 0.025	9.89 ± 0.092	9.77 ± 0.047	9.20 ± 0.018	8.65 ± 0.025

Table 11: Changes in Viscosity (cp) During Refrigerated and Ambient Storage

Beverage	Refrig. Day 0	Day 7	Day 14	Day 21	Ambient Day 0	Day 3	Day 5	Day 7
White rice	28.35 ± 0.022	28.33 ± 0.019	29.09 ± 0.026	31.18 ± 0.007	28.35 ± 0.067	28.01 ± 0.044	27.79 ± 0.006	27.18 ± 0.077
Red rice	28.97 ± 0.078	28.84 ± 0.025	29.11 ± 0.065	33.04 ± 0.008	28.97 ± 0.032	28.61 ± 0.020	28.24 ± 0.005	28.17 ± 0.098
Finger millet	35.24 ± 0.011	35.40 ± 0.029	36.01 ± 0.016	36.84 ± 0.030	35.24 ± 0.015	35.17 ± 0.020	35.83 ± 0.026	35.55 ± 0.029
Pearl millet	33.20 ± 0.033	33.34 ± 0.017	33.88 ± 0.036	34.50 ± 0.019	33.20 ± 0.110	33.08 ± 0.117	32.75 ± 0.032	32.29 ± 0.102
Sorghum	34.01 ± 0.044	34.05 ± 0.036	34.74 ± 0.081	35.24 ± 0.011	34.01 ± 0.028	33.65 ± 0.006	33.31 ± 0.088	33.01 ± 0.017
Barley	27.70 ± 0.087	28.11 ± 0.021	28.99 ± 0.015	29.75 ± 0.060	27.70 ± 0.115	27.44 ± 0.121	26.94 ± 0.115	26.38 ± 0.066

Table 12: Presumptive LAB Viability During Refrigerated and Ambient Storage (CFU/ml)

Beverage	Refrig. Day 0	Day 7	Day 14	Day 21	Ambient Day 0	Day 3	Day 5	Day 7
White rice	$4.2 \times 10^9 \pm 0.019$	$1.2 \times 10^9 \pm 0.079$	$7.8 \times 10^8 \pm 0.107$	$2.7 \times 10^7 \pm 0.085$	$4.2 \times 10^9 \pm 0.019$	$1.4 \times 10^8 \pm 0.120$	$8.4 \times 10^6 \pm 0.078$	$9.5 \times 10^5 \pm 0.170$
Red rice	$6.4 \times 10^9 \pm 0.019$	$3.4 \times 10^9 \pm 0.028$	$5.5 \times 10^8 \pm 0.081$	$7.2 \times 10^6 \pm 0.121$	$6.4 \times 10^9 \pm 0.019$	$1.2 \times 10^7 \pm 0.021$	$7.0 \times 10^6 \pm 0.054$	$3.9 \times 10^5 \pm 0.015$
Finger millet	$10.6 \times 10^9 \pm 0.019$	$4.0 \times 10^9 \pm 0.011$	$2.5 \times 10^8 \pm 0.092$	$1.2 \times 10^7 \pm 0.167$	$10.6 \times 10^9 \pm 0.019$	$5.2 \times 10^8 \pm 0.012$	$6.6 \times 10^6 \pm 0.022$	$8.0 \times 10^5 \pm 0.072$
Pearl millet	$7.8 \times 10^9 \pm 0.139$	$2.1 \times 10^9 \pm 0.055$	$2.9 \times 10^7 \pm 0.036$	$5.2 \times 10^6 \pm 0.036$	$7.8 \times 10^9 \pm 0.139$	$3.8 \times 10^7 \pm 0.031$	$3.0 \times 10^6 \pm 0.025$	$5.2 \times 10^5 \pm 0.022$
Sorghum	$3.1 \times 10^9 \pm 0.019$	$8.2 \times 10^8 \pm 0.042$	$4.9 \times 10^7 \pm 0.089$	$5.9 \times 10^6 \pm 0.071$	$3.1 \times 10^9 \pm 0.019$	$2.3 \times 10^8 \pm 0.003$	$5.5 \times 10^7 \pm 0.020$	$9.9 \times 10^5 \pm 0.087$
Barley	$6.3 \times 10^9 \pm 0.019$	$1.9 \times 10^8 \pm 0.145$	$3.6 \times 10^7 \pm 0.179$	$6.4 \times 10^6 \pm 0.209$	$6.3 \times 10^9 \pm 0.019$	$4.2 \times 10^7 \pm 0.145$	$8.5 \times 10^6 \pm 0.033$	$7.4 \times 10^5 \pm 0.079$

CONCLUSION

Fermented cereal-based beverages were developed from white rice, red rice, sprouted finger millet, pearl millet, sorghum and barley using naturally derived mixed starter cultures and plant-based milks. Cereal substrate and formulation influenced physicochemical, microbial and sensory characteristics, and the finger millet-based formulation showed comparatively favourable sensory acceptability within the trained-panel assessment. Microorganisms recovered on MRS agar are appropriately described as presumptive LAB because the starter microorganisms were not purified, identified or functionally characterized. Consequently, the present study does not establish strain-specific probiotic functionality.

The principal limitations are the undefined mixed starter culture, absence of strain-level identification, incomplete documentation of unfermented controls and storage design, limited microbiological safety assessment and small trained sensory panel. Future studies should include molecular identification and functional characterization of starter microorganisms, appropriate controls, broader pathogen and spoilage-microorganism testing, independent production batches, systematic refrigerated shelf-life evaluation and larger sensory studies before commercial probiotic or health claims are considered.

5. Acknowledgement

The authors sincerely thank Laxminarayan Innovation Technological University for providing the facilities and support required to carry out this research work.

6. Funding

No funding was received for this study.

7. Declarations

Conflict of interest: The authors declare no conflict of interest.

Ethics and consent: Informed consent was obtained from all panellists included in the study.

Data availability: All data generated or analysed during this study are included in this article and its supplementary information files.

Consent for publication: The authors consent to publication of the manuscript.

REFERENCES

1. Hill C, Guarner F, Reid G, Gibson GR, Merenstein DJ, Pot B, Morelli L, Canani RB, Flint HJ, Salminen S, Calder PC, Sanders ME (2014) The International Scientific Association for Probiotics and Prebiotics consensus statement on the scope and appropriate use of the term probiotic. Nat Rev Gastroenterol Hepatol 11:506–514. https://doi.org/10.1038/nrgastro.2014.66
2. Mridula D, Sharma M (2015) Development of non-dairy probiotic drink utilizing sprouted cereals, legume and soymilk. LWT Food Sci Technol 62:482–487. https://doi.org/10.1016/j.lwt.2014.07.011
3. Kandylis P, Pissaridi K, Bekatorou A, Kanellaki M, Koutinas AA (2016) Dairy and non-dairy fermented cereal-based beverages. Curr Opin Food Sci 7:58–63. https://doi.org/10.1016/j.cofs.2015.11.012
4. Shori AB (2016) Influence of food matrix on the viability of presumptive LAB: a review based on dairy and non-dairy beverages. Food Biosci 13:1–8. https://doi.org/10.1016/j.fbio.2015.11.001
5. Fasreen MMF, Perera ODAN, Weerahewa HLD (2017) Development of finger millet based fermented cereal-based beverage using Lactobacillus casei 431®. OUSL J 12 (1):128. https://doi.org/10.4038/ouslj.v12i1.7384
6. Aspri M, Papademas P, Tsaltas D (2020) Review on non-dairy probiotics and their use in non-dairy based products. Fermentation 6:30. https://doi.org/10.3390/fermentation6010030
7. Mali SD, Deshpande HW, Toshniwal DD, Sawate AR (2020) A review on millet based fermented cereal-based beverages. Int J Chem Stud 8 (2):968–972. https://doi.org/10.22271/chemi.2020.v8.i2o.8892
8. Ziarno M, Cichońska P (2021) Lactic acid bacteria-fermentable cereal- and pseudocereal-based beverages. Microorganisms 9:2532. https://doi.org/10.3390/microorganisms9122532
9. Ilango S, Antony U (2021) presumptive LAB from non-dairy traditional fermented foods. Trends Food Sci Technol 118:617–638. https://doi.org/10.1016/j.tifs.2021.05.034
10. Küçükgöz K, Trząskowska M (2022) Nondairy probiotic products: functional foods that require more attention. Nutrients 14:753. https://doi.org/10.3390/nu14040753
11. Horlacher N, Oey I, Agyei D (2023) Learning from tradition: health-promoting potential of traditional lactic acid fermentation to drive innovation in fermented plant-based dairy alternatives. Fermentation 9:452. https://doi.org/10.3390/fermentation9050452
12. Kitessa DA (2024) Review on effect of fermentation on physicochemical properties, anti-nutritional factors and sensory properties of cereal-based fermented foods and beverages. Ann Microbiol 74. https://doi.org/10.1186/s13213-024-01763-w
13. Gebre TS, Emire SA, Aloo SO, Chelliah R, Vijayalakshmi S, Oh DH (2024) Unveiling the potential of African fermented cereal-based beverages: probiotics, functional drinks, health benefits and bioactive components. Food Res Int 191:114656. https://doi.org/10.1016/j.foodres.2024.114656
14. Ghoshal G, Kamboj J, Kaur P (2024) Pearl millet flour and green gram milk based fermented cereal-based beverage. Int J Food Microbiol 417:110696. https://doi.org/10.1016/j.ijfoodmicro.2024.110696
15. Chen Y, Guo J, Xiang M, Tian Z, Niu J, Cheng W, Gao F (2026) A comprehensive review of lactic acid bacteria-fermented plant-based beverages: substrate types, nutritional quality, probiotic characteristics, metabolic pathways and future development trends. Crit Rev Food Sci Nutr 66 (16):2993–3021. https://doi.org/10.1080/10408398.2025.2589965
16. AOAC INTERNATIONAL (2019) Official Methods of Analysis of AOAC INTERNATIONAL, 21st edn. Latimer GW Jr

(ed). AOAC INTERNATIONAL, Rockville, MD, USA. Methods 925.10, 920.87, 920.39, 923.03 and 985.29.

17. ISO (2013) ISO 4833-1:2013. Microbiology of the food chain—Horizontal method for the enumeration of microorganisms—Part 1: Colony count at 30 °C by the pour plate technique. International Organization for Standardization, Geneva, Switzerland.
18. ISO (2006) ISO 4832:2006. Microbiology of food and animal feeding stuffs—Horizontal method for the enumeration of coliforms—Colony-count technique. International Organization for Standardization, Geneva, Switzerland.
19. ISO (2008) ISO 21527-1:2008. Microbiology of food and animal feeding stuffs—Horizontal method for the enumeration of yeasts and moulds —Part 1: Colony count technique in products with water activity greater than 0.95. International Organization for Standardization, Geneva, Switzerland.
20. Tamime AY, Robinson RK (2007) Tamime and Robinson's Yoghurt: Science and Technology, 3rd edn. Woodhead Publishing, Cambridge, UK.
21. Chandan RC, Kilara A (eds) (2013) Manufacturing Yogurt and Fermented Milks, 2nd edn. Wiley-Blackwell, Ames, IA, USA.
22. Sodini I, Remeuf F, Haddad S, Corrieu G (2004) The relative effect of milk base, starter, and process on yogurt texture: a review. Crit Rev Food Sci Nutr 44 (2):113–137. https://doi.org/10.1080/10408690490424793
23. Lee WJ, Lucey JA (2010) Formation and physical properties of yogurt. Asian-Australas J Anim Sci 23 (9):1127–1136. https://doi.org/10.5713/ajas.2010.r.05
24. Walstra P, Wouters JTM, Geurts TJ (2006) Dairy Science and Technology, 2nd edn. CRC Press, Boca Raton, FL, USA.
25. ICMSF (International Commission on Microbiological Specifications for Foods) (2005) Microorganisms in Foods 6: Microbial Ecology of Food Commodities, 2nd edn. Springer, New York, NY, USA.
26. APHA (American Public Health Association) (2015) Compendium of Methods for the Microbiological Examination of Foods, 5th edn. Salfinger Y, Tortorello ML (eds). APHA Press, Washington, DC, USA.
27. Holzapfel WH, Haberer P, Geisen R, Björkroth J, Schillinger U (2001) Taxonomy and important features of probiotic microorganisms in food and nutrition. Am J Clin Nutr 73 (2 Suppl):365S–373S. https://doi.org/10.1093/ajcn/73.2.365s
28. Leroy F, De Vuyst L (2004) Lactic acid bacteria as functional starter cultures for the food fermentation industry. Trends Food Sci Technol 15 (2):67–78. https://doi.org/10.1016/j.tifs.2003.09.004
29. Fleet GH (1990) Yeasts in dairy products. J Appl Bacteriol 68 (3):199–211. https://doi.org/10.1111/j.1365-2672.1990.tb02566.x
30. Axelsson L (2004) Lactic acid bacteria: classification and physiology. In: Salminen S, von Wright A, Ouwehand A (eds) Lactic Acid Bacteria: Microbiological and Functional Aspects, 3rd edn. Marcel Dekker, New York, NY, USA, pp 1–66.
31. Gupta R, Gaur S (2025) Deciphering the effect of millet type on the structure of the bacterial community in an Indian fermented beverage. Food Saf Health 3 (3):455–465. https://doi.org/10.1002/fsh3.70010
32. Udeh HO, Duodu KG, Jideani AIO (2025) Effect of fermentation time on the physicochemical properties and phenolic composition of malted finger millet beverages. Food Sci Nutr 13 (3):e4659. https://doi.org/10.1002/fsn3.4659
33. Peyer LC, Zannini E, Arendt EK (2016) Lactic acid bacteria as sensory biomodulators for fermented cereal-based beverages. Trends Food Sci Technol 54:17–25. https://doi.org/10.1016/j.tifs.2016.05.009
34. Rani M, Dabur RS, Bishnoi S, Jairath G (2024) Influence of storage on physico-chemical physiognomies of fermented whey cereal (pearl millet and moth bean) beverage. J Food Sci Technol 61 (1):117–128. https://doi.org/10.1007/s13197-023-05825-w

HOW TO CITE: Vaidehi Mande, Sneha Karadbhajne, Quality Characteristics and Storage Stability of Fermented Cereal-Based Beverages Produced Using a Curd-Derived Undefined Mixed Starter Culture, Int. J. Sci. R. Tech., 2026, 3 (11), 1147-1167. https://doi.org/10.5281/zenodo.24470193