LWT - Food Science and Technology 218 (2025) 117505

Contents lists available at ScienceDirect

LWT

journal homepage: www.elsevier.com/locate/lwt

Sustainable innovations in Kurut drink production through replacing water with dairy whey to improve nutritional quality

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ARTICLE INFO

Keywords:
Kurut drink
Whey valorization
Sustainability
Nutritional properties
Central Asia

ABSTRACT

This study investigates a sustainable innovation in traditional Kurut drink production, providing insights into integrating environmental and nutritional strategies into the dairy industry. The objective was to conserve drinking water, valorize dairy whey and its permeate, and enhance the nutritional properties of the final product. Kurut, sourced from a manufacturing plant in Kyrgyzstan, was processed using methods replicating factory production with various liquid mediums. Physicochemical and sensory properties of water-based Kurut were compared with samples made using acid whey, sweet whey, and their permeates. Results showed that acid whey and its permeates improved consumer preference over water-based Kurut, offering a sustainable method to reduce waste and enhance product value. Whey incorporation enriched the amino acid profile, boosting essential nutrients. Although slightly less preferred, sweet whey-based Kurut contained higher mono- and polyunsaturated fatty acids, appealing to heart-health-focused markets. This innovation reinvents a traditional drink, restoring its milk-derived nutritional value and providing a viable pathway for the dairy industry to create sustainable, nutritious, and health-oriented products. The findings demonstrate how traditional practices can integrate modern sustainability and nutritional strategies to address environmental and consumer needs.

1. Introduction

Kurut can be described as one of the oldest “cheeses” in the world, with a recipe that has been passed down by the nomadic peoples of Central Asia for thousands of years. Kurut is a type of fermented dairy product, typically made by drying yogurt or ayran (a yogurt-based drink) after filtration, followed by the addition of salt and shaping into small balls (Kochkorova & Kitarova, 2021). This product is cherished for its rich cultural history, unique traditional preparation methods, and notable nutritional value (Tuganbay et al., 2022). Importantly, it served as a portable and long-lasting source of nourishment, making it essential for nomadic lifestyles prevalent in Central Asia (Konuspayeva et al., 2023).

While traditional Kurut is widespread in the Middle East, West Asia, Central Asia, and Eastern Europe, liquid Kurut as a drink was unique only to Kyrgyz nomads, and even there it was nearly forgotten. Globalization and mass production processes have contributed to the near loss of the authentic Kurut drink. The only company in Kyrgyzstan managed to revive this traditional drink using knowledge from older generations who remembered the original preparation methods, and it has started producing it on industrial way. Although the recipe and methods were designed to closely match the authentic taste of the drink, there has been no formal scientific research conducted to verify or enhance its nutritional and sensory attributes.

To further enhance the sustainability of this revival, the substitution of water with whey and whey permeate in the production of liquid Kurut is explored. This innovative approach not only utilizes byproducts of the dairy industry, reducing environmental waste, but also potentially enriches the nutritional profile of the drink (Smithers, 2008). Utilizing whey and it’s permeate aligns with circular economy principles (Blasi

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https://doi.org/10.1016/j.lwt.2025.117505
Received 25 November 2024; Received in revised form 31 January 2025; Accepted 6 February 2025
Available online 7 February 2025

et al., 2022), promoting the value-added reuse of what would otherwise be waste products in a manner that contributes to more sustainable food production practices. The principles of circular economy emphasize transforming industrial waste into valuable resources, a strategy increasingly essential in addressing global sustainability challenges (Kennedy & Linnenluecke, 2022). Despite their cultural significance and widespread consumption, there is still much to uncover about Kyrgyz Kurut and Kurut drink. Research on these traditional dairy products remains relatively limited, with gaps in understanding their microbial composition, nutritional content, sensory characteristics, and potential health effects.

In modern society, the relentless focus on cost reduction and the substitution of natural ingredients in food has often overshadowed the benefits of traditional recipes. This trend, driven by rapid population growth in recent decades, contrasts with the need to preserve and adapt these recipes for modern needs. However, events like COVID-19, wars, and conflicts underscore the importance of reconsidering traditional national recipes crafted over millennia by our ancestors. These traditional recipes, frequently overlooked by scientific research, offer a wealth of opportunities for future discoveries. The challenge for future researchers is to merge ancient practices with modern science and technology, scaling historical zero-waste food production to meet global needs. This perspective aligns with themes discussed in prior studies on the revitalization of indigenous food practices and ecological knowledge in Canada and the United States (Coté, 2016). Thus, the aim of this study was to assess the physicochemical, sensory, and microbiological profiles of the traditional water-based Kyrgyz Kurut drink by replacing the water with acid whey, sweet whey, and their permeates. This approach highlights the potential for enhancing the nutritional and functional value of traditional fermented beverages while addressing sustainable use of by-products like whey. By exploring this novel modification, our study serves as an example of how to integrate the past with the present.

2. Materials and methods

2.1. Materials

Kurut (K; 3.5 g/100 g fat, 58.5 g/100 g protein, 10.5 g/100 g carbohydrates, 11.0 g/100 g minerals) for the experiments was provided in its original ball form by the dairy plant Alaiku Organics Company (Osh, Kyrgyzstan). It was selected from a random batch with a packaging date of November 18, 2023 and stored at a refrigerated temperature of +6 °C to +8 °C until use.

Liquid bovine acid whey (AW; 6.39 g/100 g dry matter, 0.9 g/100 g protein, 0.35 g/100 g fat, and 4.52 g/100 g other solids) a by-product of fresh curd production, and acid whey permeate (AWP; 5.71 g/100 g dry matter, 0.42 g/100 g protein, 0.09 g/100 g fat and 4.49 g/100 g other solids) were supplied from dairy plant AB Kauno pienas (Kaunas, Lithuania). AWP was obtained through ultrafiltration of fresh acid whey left after curd production. Liquid bovine sweet whey (SW; 6.95 g/100 g dry matter, 0.95 g/100 g protein, 0.23 g/100 g fat, and 5.7 g/100 g other solids), a by-product of rennet cheese production, and its permeate (SWP; 4.43 g/100 g dry matter, 0.5 g/100 g protein, 0.03 g/100 g fat and 3.8 g/100 g other solids) were supplied by the dairy plant AB Vilvi group (Vilkyškiai, Lithuania). All whey and permeates were stored frozen at −15 °C until use. Prior to drink preparation, the whey and permeates were thawed at 4 °C.

2.2. Production of Kurut drink

The Kurut balls were ground using a Bosch MKM6003 grinder (Republic of Slovenia) for 3 min to obtain a fine powder. The Kurut powder (K) was then mixed in a 1:10 ratio with various liquid mediums: tap water (K-W), acid whey (K-AW), acid whey permeate (K-AWP), sweet whey (K-SW), and sweet whey permeate (K-SWP). All samples were homogenized for 10 min at 15,000 rpm to ensure proper dispersion of the Kurut powder. Pasteurization was performed in water bath for 20 min at temperature of 80 °C. After cooling the samples to 45 °C, 15 ml of each drink were distributed in sterile tubes and stored at refrigerated conditions for microbiological analysis over 180 days. The remaining samples were transferred in tightly sealed glass containers and stored at 5 °C for determination of physicochemical and sensory parameters on days 1, 90 and 180. The technological process is illustrated in Fig. 1.

2.3. Determination of physicochemical properties

The nutritional composition, color, fatty acid, amino acid, and sensory profiles of Kurut drinks were analyzed in triplicate on day 1. Various parameters including dry matter, moisture, acidity, ash, fat, and protein were assessed using prescribed methods: ISO 5534:2004 (International Organization for Standardization, 2004b) for dry matter and moisture, AOAC (2005) (AOAC International, 2005) for ash, ISO 1735:2004 (International Organization for Standardization, 2004a) for fat, ISO 22662:2007 (International Organization for Standardization, 2007) for lactose, and ISO 8968–3:2004 (International Organization for Standardization, 2004c) for protein.

Color characteristics were evaluated using a portable colorimeter PCE-CSM5 (PCE instruments, UK) with a CIE L^* a^* b^* C^*H^* option (where L^* = lightness, a^* = green–red color, and b^* = blue–yellow color, c^* = Chroma, H^* = hue angle referring to the degree of the dominant spectral component (red, green, and blue) and ranges from 0° to 360°, and the c^* (chroma) = represents the saturation of a color). The overall color difference (ΔE) during sample storage was calculated using the following formula (Mileriene, Serniene, Henriques, et al., 2021): $\Delta E = [(L - L_0)^2 + (a - a_0)^2 + (b - b_0)^2]1/2$, where L_0, a_0, and b_0 are values of day 1 and L, a, and b are the values measured throughout the storage period.

The pH, overall acceptability, and color change were determined on days 1, 90, and 180. The pH was directly measured using a pH meter (Sartorius Professional meter for pH Measurement, Germany).

2.4. Determination of fatty acid profile

The analysis for the identification and quantification of fatty acids (FA) was conducted via gas chromatography utilizing a capillary column and flame-ionization detection. Initially, FAs were extracted from a 2 g sample using 15 mL of n-hexane (Chempur, Piekary Śląskie, Poland), followed by methylation with anhydrous KOH methanol solution to yield methyl esters, following the protocol ISO 12966–2:2017 (International Organization for Standardization, 2017). The analysis of FA methyl esters was carried out using a Shimadzu GC-2010 gas chromatograph (Shimadzu Corporation, Kyoto, Japan) equipped with a flame ionization detector (FID) and a 100 m column Restek Rt-2560 (Restek, Bellefonte, PA), with a diameter of 0.25 μm and thickness of 0.20 μm, as specified in ISO 12966–4:2015 (International Organization for Standardization, 2015). Chromatographic peaks were identified by comparing retention times with a mixture of Supelco 37 Component FAME Mix reagent kit (Supelco Analytical Bellefonte, PA, USA). The analytical conditions were as follows: a volume of 1 μL was injected; the column temperature was initially set at 100 °C for 4 min, then ramped up to 240 °C at a rate of 13 °C/min and maintained for 63 min. The injector temperature was set at 250 °C and the detector temperature at 300 °C. Nitrogen was employed as the carrier gas.

Each fatty acid was expressed in g/100 g of total fatty acid content. Based on the presence and the number of single and double bonds, fatty acids were grouped into the following categories: saturated fatty acids (SFA), unsaturated fatty acids (UFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA), omega−3 fatty acids (n3PUFA) and omega−6 fatty acids (n6PUFA). Health lipid indices, indicating the quality in terms for pro-atherogenicity, pro-thrombogenicity, and cardiovascular health risks, were calculated as follows (Ulbricht & Southgate, 1991):

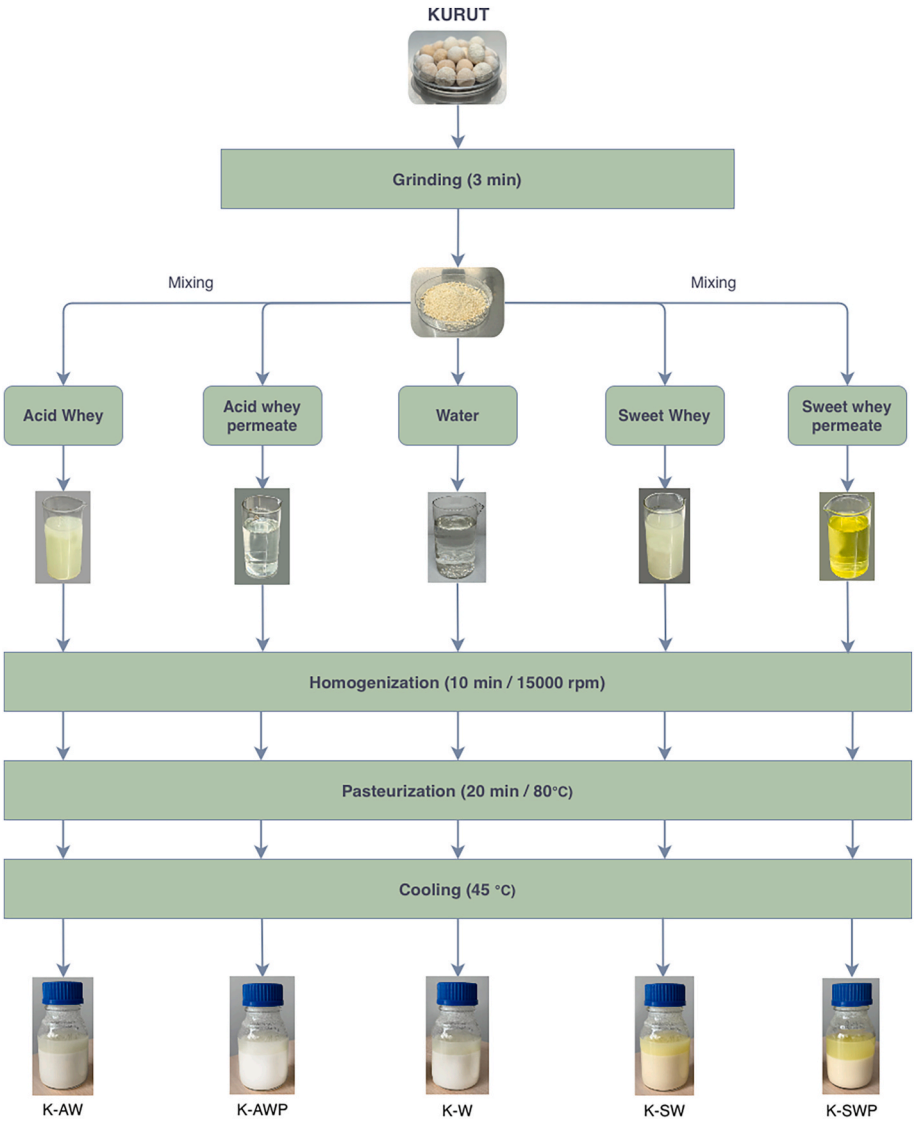

Fig. 1. Schematic principle of Kurut drink production.

Index of atherogenicity (AI) = (C12:0 + (4 x C14:0) + C16:0)/(PUFA + MUFA);

Index of thrombogenicity (TI) = (C12:0 + C16:0 + C18:0) / ((0.5 x MUFA) + (0.5 x n6PUFA) + (3 x n3PUFA) + (n3PUFA / n6PUFA));

Hypocholesterolemic and hypercholesterolemic ratio (h/H) = (C18:1 + PUFA) / (C14:0 + C16:0);

Desirable fatty acids (DFA) = UFA + C18:0.

2.5. Determination of amino acid profile

The amino acid (AA) compositions of the samples were analyzed using ultrafast liquid chromatography (UFLC) with automated o-phthalaldehyde (OPA)/9-fluorenylmethyl chloroformate (FMOC)/mercaptopropionic acid (MERC) derivatization. Standard solutions of amino acids, including alanine (ALA), aspartic acid (ASP), arginine (ARG), cystine (CYS), glycine (GLY), valine (VAL), leucine (LEU), isoleucine (ILE), threonine (THR), serine (SER), proline (PRO), methionine (MET), glutamic acid (GLU), phenylalanine (PHE), lysine (LYS), histidine (HIS), tyrosine (TYR), asparagine (ASP), and tryptophan (TRP) were used for this analysis (A9781 Sigma-Aldrich, Darmstadt, Germany).

Each sample (approximately 0.4 g) underwent hydrolysis with 25 mL of 6 M HCl for 24 h at 103 °C. The resultant contents were quantitatively transferred into a 250 ml beaker using a 150–200 ml solution of 0.2 mol Na+/l, pH 2.20 trisodium citrate dihydrate. The resulting hydrolysate was partially neutralized by the gradual addition of 17 ml of 7.5 N sodium hydroxide solution while stirring continuously, ensuring the temperature remained below 40 °C (in a cold-water bath). The pH was adjusted to 2.20 at room temperature using 7.5 N sodium hydroxide solution.

Before injection, all samples were filtered through 0.45-μm filters (Merck Millipore, Darmstadt, Germany). The amino acids were separated using a UHPLC column YMC-Triart C18 (1.9 μm, YMC co. ltd. Kyoto, Japan) on a UFLC instrument (Shimadzu, Japan), which was equipped with a fluorescence detector RF-20Axs and a pre-treatment function-equipped automatic injector SIL-30AC (Shimadzu, Japan). The analytical conditions were as follows: the mobile phase consisted of solvent A (20 mmol/L potassium phosphate buffer, pH 6.5) and solvent B (45/40/15 acetonitrile/methanol/water); flow rate was set at 0.5 mL/min, and the column temperature was maintained at 45 °C. Detection wavelengths were set as follows: RF-20Axs Ex. at 350 nm, Em. at 450 nm to Ex. at 266 nm, Em. at 305 nm (9.0 min). A calibration set comprising five levels was utilized, covering a concentration range of 9.375–150.00

μmol/L, except for cysteine, which covered a concentration range of 8.08–75.00 μmol/L.

2.6. Assessment of sensory profile

The sensory profile assessment of Kurut drinks involved the evaluation of various attributes by a trained panel of seven members, conducted in accordance with the guidelines outlined in ISO 8586:2012 (International organisation for standartization, 2012). A quantitative descriptive analysis (QDA) was performed to assess the selected sensory attributes of drinks. A semi-trained panel underwent re-training across three sessions to familiarize themselves with the evaluation of sensory characteristics. During these sessions, the panelists evaluated the samples and generated descriptors for descriptive analysis. Through open discussion, nine sensory attributes were identified (Table 6). In the QDA assessment, each panelist evaluated five samples of drinks presented in random order and identified with 3-digit random numbers. Panelists rated the attributes of each sample using a 1–10 intensity scale. Three tasting sessions were conducted as replicates to ensure consistency and accuracy in the sensory evaluation.

2.7. Microbiological profile

The microbiological analysis involved determining the viable counts of total bacteria, lactic acid bacteria (LAB), enterobacteria, coliforms, yeasts, and molds in triplicate at different storage time points (Day 1, 90, and 180). Specific selective media and incubation conditions were used for the enumeration of each microorganism group, following the methodology outlined by Mileriene, Serniene, Henriques, et al. (2021). Total bacteria were enumerated using Plate Count Agar (PCA, Biolab, Budapest, Hungary) with the pour-plate technique. The plates were incubated at 30 °C for 48 h. LAB were cultured on M17 agar (Oxoid, Basingstoke, UK) supplemented with 10 g/100 ml lactose solution (Sigma-Aldrich, Buchs, Switzerland). Enumeration was conducted after incubation at 37 °C for 48 h using the surface plating technique. Enterobacteria were enumerated using violet red bile glucose agar (VRBGA, Sigma-Aldrich, Buchs, Switzerland) with the pour-plate technique. Plates were incubated at 37 °C for 24 h. Coliforms were determined on violet red bile agar (VRBA, Sigma-Aldrich, Buchs, Switzerland) using the pour-plate technique. Enumeration was carried out after incubation at 30 °C for 24 h. Yeast and mold counts were conducted using yeast extract glucose chloramphenicol agar (YGC, Sigma-Aldrich, Buchs, Switzerland). Plates were incubated at 30 °C for 72 h using the surface plating technique.

2.8. Statistical analysis

The statistical analysis was performed using SPSS statistical package (Version 24, SPSS Inc., Chicago, IL, USA). Descriptive statistics were generated using the Explore function, and a one-way analysis of variance (ANOVA) was applied to evaluate the data. Pairwise mean differences were assessed using the Tukey test with confidence intervals. All statistical analyses were conducted at a 95% significance level.

3. Results

3.1. Nutritional composition

Five Kurut drink samples were compared for their content of dry matter, fats, proteins, ash, carbohydrates, and their energy values (Table 1). The treatment significantly affected all measured variables ($p \leq 0.05$). Whey initially had a higher protein content, resulting in greater protein levels in the whey-based Kurut samples (K-AW, K-SW) compared to other samples ($p \leq 0.05$). Among the whey-based samples, Kurut made from sweet whey (K-SW) exhibited the highest levels of dry matter, carbohydrates, protein, and energy value ($p \leq 0.001$). In contrast, the water-based Kurut sample had the lowest compositional parameters.

3.2. Fatty acid profile

Table 2 presents the fatty acid content (g/100 g of total fatty acid content) in five different samples of Kurut drinks. The Dietary Guidelines advise restricting the consumption of saturated fatty acids (SFAs) to less than 10% of daily energy intake and suggest replacing dietary SFAs with unsaturated fatty acids while adopting a healthy dietary pattern. Two fatty acids, C16:0 (palmitic acid) and C18:1 (oleic acid) showed significant variation among samples: C16:0 was highest in K-SW, while C18:1 differed significantly across almost all samples, with K-SW again showing higher levels. Oleic acid is particularly noted for its beneficial effects on heart health. Sweet whey based Kurut drink (K-SW) demonstrated significantly lower levels of SFA and higher levels of unsaturated (UFA, 41.71 g/100 g), monounsaturated (MUFA, 34.29 g/100 g), polyunsaturated FA (PUFA, 5.4 g/100 g), Omega-3 (1.02 g/100 g), Omega-6 (4.87 g/100 g) and Omega-9 (32.42 g/100 g), offering a healthier fatty acid profile compared to the other samples ($p \leq 0.05$).

Calculated atherogenic index (AI) measures the potential risk of developing atherosclerosis. The lowest AI values were detected in K-SW (1.57 ± 0.01), followed by K-SWP (2.31 ± 0.01), suggesting a lower potential for developing atherosclerosis compared to K-AW (2.65) ($p \leq 0.05$).

Specific omega-3 fatty acids are essential nutrients with numerous health benefits, particularly in reducing inflammation, supporting cardiovascular health, and promoting brain function. Eicosapentaenoic acid (EPA) is known for its anti-inflammatory properties, docosahexaenoic acid (DHA) is critical for brain function, eye health, and fetal development, while docosapentaenoic acid (DPA) is less well-known compared to EPA and DHA and can be synthesized in the body from EPA (Dyall, 2015). EPA and DHA were below detection levels in our samples, but the level of DPA was lower in K-SW compared to the other samples ($p \leq 0.05$).

The thrombogenic index (TI), which helps assess the risk of thrombosis, demonstrated lower values in K-SW (2.16) and K-SWP (2.32) indicating lower likelihood of thrombus formation compared to K-AW (2.72) ($p \leq 0.05$). A lower TI is associated with a reduced risk of cardiovascular events (Ulbricht & Southgate, 1991).

The h/H ratio was calculated as the ratio of fatty acids that lower and increase blood cholesterol levels (Santos-Silva et al., 2002). We found the best h/H values in K-SWP (0.38), suggesting a better balance compared to K-AW (0.32) ($p \leq 0.05$). A higher h/H ratio is desirable for

Table 1
Composition and energy values of Kurut drinks.

	K-W	K-AW	K-AWP	K-SW	K-SWP
Dry matter (g/100 g)	7.48 ± 0.07^{a}	13.70 ± 0.02^{b}	12.42 ± 0.04^{c}	16.72 ± 0.04^{d}	13.39 ± 0.03^{e}
Fats (g/100 g)	0.30 ± 0.02^{a}	0.70 ± 0.02^{b}	0.51 ± 0.03^{c}	0.70 ± 0.03^{b}	0.46 ± 0.03^{c}
Proteins (g/100 g)	5.32 ± 0.02^{a}	5.74 ± 0.03^{b}	5.42 ± 0.01^{c}	6.14 ± 0.03^{d}	5.40 ± 0.02^{c}
Ash (g/100 g)	0.95 ± 0.02^{a}	1.52 ± 0.02^{b}	1.55 ± 0.02^{b,c}	1.64 ± 0.07^{c,d}	1.65 ± 0.03^{d}
Carbohydrates (g/100 g)	0.92 ± 0.09^{a}	5.75 ± 0.03^{b}	4.94 ± 0.02^{c}	8.24 ± 0.03^{d}	5.89 ± 0.02^{e}
Energy value (kCal/100 g)	28.0 ± 0.1^{a}	51.93 ± 0.06^{b}	46.0 ± 0.1^{c}	64.0 ± 0.1^{d}	49.0 ± 0.1^{e}

*Different superscript letters indicate statistically significant differences among samples ($p \leq 0.05$).

Table 2
Composition of fatty acids in Kurut drinks.

Fatty acids (g/100 g total FA)	K-W	K-AW	K-AWP	K-SW	K-SWP
C4:0	3.16 ± 0.09[a]	3.15 ± 0.21[a]	3.15 ± 0.25[a]	1.42 ± 0.17[b]	2.67 ± 0.11[c]
C6:0	1.86 ± 0.02[a]	1.82 ± 0.07[a]	1.78 ± 0.04[a]	0.9 ± 0.1[b]	1.86 ± 0.04[a]
C8:0	0.92 ± 0.01[a]	0.93 ± 0.02[a]	0.88 ± 0.04[a]	0.41 ± 0.05[b]	0.92 ± 0.03[a]
C10:0	2.03 ± 0.02[a]	2.26 ± 0.1[b]	2.08 ± 0.03[a]	0.96 ± 0.04[c]	2.01 ± 0.04[a]
C11:0	0.16 ± 0.01[a]	0.3 ± 0.03[b]	0.29 ± 0.02[b]	0.14 ± 0.01[a]	0.19 ± 0.06[a]
C12:0	2.53 ± 0.04[a]	2.85 ± 0.02[b]	2.59 ± 0.01[a]	1.37 ± 0.03[c]	2.54 ± 0.03[a]
C13:0	0.13 ± 0.01[a]	0.15 ± 0.01[a]	0.14 ± 0.01[a]	0.06 ± 0.01[b]	0.13 ± 0.02[a]
C14:0	10.67 ± 0.12[a]	10.82 ± 0.03[ab]	10.83 ± 0.02[ab]	6.16 ± 0.04[c]	10.62 ± 0.03[a]
C14:1	1.0 ± 0.01[a]	0.93 ± 0.01[b]	1.0 ± 0.01[a]	0.5 ± 0.01[c]	0.98 ± 0.01[a]
C14:2	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	1.7 ± 0.01[b]
C15:0	1.71 ± 0.01[a]	1.34 ± 0.02[b]	1.64 ± 0.01[c]	0.9 ± 0.0[d]	0.0 ± 0.0[e]
C16:0	29.54 ± 0.15[a]	31.73 ± 0.11[b]	29.89 ± 0.01[c]	36.24 ± 0.02[d]	29.45 ± 0.04[a]
C16:1	2.11 ± 0.07[a]	2.1 ± 0.01[a]	2.15 ± 0.02[a]	1.2 ± 0.01[b]	2.16 ± 0.01[a]
C17:0	1.03 ± 0.02[a]	0.8 ± 0.02[b]	1.0 ± 0.01[a]	0.56 ± 0.02[c]	1.04 ± 0.01[ab]
C17:1	0.37 ± 0.0[a]	0.25 ± 0.01[b]	0.34 ± 0.01[c]	0.17 ± 0.0[d]	0.37 ± 0.0[a]
C18:0	10.7 ± 0.05[a]	10.79 ± 0.06[ab]	10.81 ± 0.01[b]	8.35 ± 0.01[c]	10.82 ± 0.02[b]
C18:1 tr.	3.57 ± 0.03[a]	2.78 ± 0.0[b]	3.56 ± 0.01[a]	1.95 ± 0.01[c]	3.67 ± 0.02[d]
C18:1	23.55 ± 0.14[a]	23.39 ± 0.16[a]	23.52 ± 0.05[a]	32.22 ± 0.13[b]	24.13 ± 0.06[c]
C18:2 tr.	0.21 ± 0.01[a]	0.11 ± 0.0[b]	0.17 ± 0.01[c]	0.07 ± 0.01[d]	0.21 ± 0.01[a]
C18:2 ω6	1.64 ± 0.09[a]	2.01 ± 0.04[b]	1.59 ± 0.01[a]	4.87 ± 0.04[c]	1.57 ± 0.01[a]
C20:0	0.27 ± 0.01[a]	0.06 ± 0.0[b]	0.17 ± 0.01[c]	0.21 ± 0.01[d]	0.25 ± 0.0[a]
C18:3 α ω3	0.86 ± 0.02[a]	0.53 ± 0.01[b]	0.78 ± 0.01[c]	0.44 ± 0.01[d]	0.89 ± 0.01[e]
C20:1	0.36 ± 0.07[a]	0.08 ± 0.07[b]	0.28 ± 0.01[a]	0.2 ± 0.0[a]	0.27 ± 0.0[a]
C21:0	1.23 ± 0.01[a]	0.68 ± 0.05[b]	1.15 ± 0.01[c]	0.58 ± 0.02[d]	1.26 ± 0.01[a]
C22:0	0.11 ± 0.01[a]	0.0 ± 0.0[b]	0.05 ± 0.01[c]	0.0 ± 0.01[b]	0.1 ± 0.0[a]
C23:0	0.05 ± 0.04[a]	0.0 ± 0.0[a]	0.01 ± 0.01[a]	0.0 ± 0.0[a]	0.05 ± 0.01[a]
C20:4 ω6	0.05 ± 0.09[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
C24:0	0.02 ± 0.01[a]	0.0 ± 0.0[b]	0.0 ± 0.0[b]	0.0 ± 0.0[b]	0.0 ± 0.0[b]
C22–5 ω3	0.15 ± 0.0[a]	0.12 ± 0.0[ab]	0.15 ± 0.0[a]	0.1 ± 0.01[b]	0.13 ± 0.02[a]
SFA	66.13 ± 0.34[a]	67.68 ± 0.14[b]	66.46 ± 0.11[a]	58.28 ± 0.13[c]	63.92 ± 0.03[d]
UFA	33.86 ± 0.34[a]	32.31 ± 0.14[b]	33.53 ± 0.11[a]	41.71 ± 0.13[c]	36.07 ± 0.03[d]
MUFA	27.4 ± 0.17[a]	26.75 ± 0.1[b]	27.29 ± 0.09[a]	34.29 ± 0.11[c]	27.91 ± 0.05[d]
PUFA	2.69 ± 0.19[a]	2.67 ± 0.04[a]	2.52 ± 0.01[a]	5.4 ± 0.04[b]	4.28 ± 0.03[c]
Omega3	1.0 ± 0.02[a]	0.66 ± 0.01[b]	0.93 ± 0.01[c]	0.53 ± 0.01[d]	1.02 ± 0.03[a]
Omega6	1.69 ± 0.17[a]	2.01 ± 0.04[b]	1.59 ± 0.01[a]	4.87 ± 0.04[c]	1.57 ± 0.01[a]
Omega9	23.91 ± 0.17[a]	23.47 ± 0.08[b]	23.79 ± 0.06[a]	32.42 ± 0.13[c]	24.39 ± 0.05[d]
Trans FA	3.77 ± 0.03[a]	2.89 ± 0.01[b]	3.73 ± 0.02[a]	2.02 ± 0.02[c]	3.88 ± 0.01[d]
C20:5 ω3 EPA	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
C22:5 ω3 DPA	0.15 ± 0.0[a]	0.12 ± 0.0[ab]	0.15 ± 0.0[a]	0.1 ± 0.01[b]	0.13 ± 0.02[a]
C22:6 ω3 DHA	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]	0.0 ± 0.0[a]
AI	2.49 ± 0.05[a]	2.65 ± 0.01[b]	2.54 ± 0.01[a]	1.57 ± 0.01[c]	2.31 ± 0.01[d]
TI	2.36 ± 0.04[a]	2.72 ± 0.0[b]	2.43 ± 0.0[c]	2.16 ± 0.01[d]	2.32 ± 0.01[a]
h/H	0.33 ± 0.01[a]	0.32 ± 0.0[b]	0.33 ± 0.0[a]	0.32 ± 0.0[b]	0.38 ± 0.0[c]
DFA	44.56 ± 0.3[a]	43.1 ± 0.2[b]	44.35 ± 0.12[a]	50.06 ± 0.14[c]	46.89 ± 0.05[d]
Omega6/Omega3	1.69 ± 0.14[a]	3.07 ± 0.07[b]	1.71 ± 0.02[a]	9.12 ± 0.13[c]	1.54 ± 0.04[a]

*Different superscript letters indicate statistically significant difference between samples ($p \leq 0.05$).

Table 3
Composition of amino acids in Kurut drinks.

Amino Acids, μmol/L	K-W	K-AW	K-AWP	K-SW	K-SWP
Non-essential					
Aspartic acid	0.45 ± 0.02[a]	0.52 ± 0.03[b]	0.43 ± 0.02[a,c]	0.51 ± 0.01[b]	0.4 ± 0.01[c]
Glutamic acid	1.15 ± 0.03[a]	1.23 ± 0.03[a]	1.09 ± 0.05[ab]	1.23 ± 0.03[a]	1.05 ± 0.01[b]
Serine	0.28 ± 0.01[a]	0.31 ± 0.0[b]	0.28 ± 0.01[a]	0.31 ± 0.01[b]	0.26±0[a]
Alanine	0.17 ± 0.0[a]	0.2 ± 0.0[b]	0.17 ± 0.01[a,c]	0.2 ± 0.01[b]	0.16 ± 0[c]
Cond. essential					
Glycine	0.09 ± 0.0[a]	0.1 ± 0.0[ab]	0.09 ± 0.01[a]	0.1 ± 0.01[a]	0.08±0[a,c]
Arginine	0.18 ± 0.0[a]	0.19 ± 0.0[a]	0.19 ± 0.02[a]	0.19 ± 0.01[a]	0.15 ± 0.02[b]
Tyrosine	0.26 ± 0.01[a]	0.27 ± 0.01[a]	0.25 ± 0.01[ab]	0.26 ± 0.01[a]	0.22 ± 0.01[b]
Cysteine	0.08 ± 0.03[a]	0.09 ± 0.04[a]	0.09 ± 0.02[a]	0.09 ± 0.03[a]	0.09 ± 0.05[a]
Proline	0.21 ± 0.09[a]	0.23 ± 0.01[a]	0.23 ± 0.06[a]	0.27 ± 0.07[a]	0.24 ± 0.05[a]
Essential					
Histidine	0.09 ± 0.02[a]	0.1 ± 0.02[a]	0.07 ± 0.01[a]	0.07 ± 0.03[a]	0.07±0[a]
Threonine	0.24 ± 0.0[a]	0.26 ± 0.01[a,c]	0.22 ± 0.01[ab]	0.26 ± 0.01[a,c]	0.21 ± 0.01[b]
Valine	0.25 ± 0.01[a]	0.27 ± 0.01[a]	0.25 ± 0.03[a]	0.28 ± 0.02[a]	0.23 ± 0.02[a]
Methionine	0.17 ± 0.03[a]	0.21 ± 0.04[a]	0.19 ± 0.03[a]	0.22 ± 0.04[a]	0.22 ± 0.04[a]
Phenylalanine	0.24 ± 0.01[a]	0.27 ± 0.02[a]	0.24 ± 0.01[a]	0.24 ± 0.01[a]	0.21±0[b]
Isoleucine	0.24 ± 0.03[a]	0.27 ± 0.01[ab]	0.24 ± 0.02[a]	0.3 ± 0.01[b]	0.23 ± 0.03[a]
Leucine	0.47 ± 0.04[a]	0.54 ± 0.01[b]	0.49 ± 0.02[ab]	0.55 ± 0.02[b]	0.45 ± 0.02[a]
Lysine	0.31 ± 0.01[a]	0.43 ± 0.02[b]	0.35 ± 0.01[ab]	0.37 ± 0.06[ab]	0.31 ± 0.01[a]

*Different superscript letters indicate statistically significant difference between samples ($p \leq 0.05$).

maintaining healthy blood cholesterol levels.

The omega-6/omega-3 ratio is important for assessing the inflammatory potential of the diet, with lower ratios generally considered more favorable for health due to the anti-inflammatory properties of omega-3 fatty acids (Simopoulos, 2002). Kurut drinks based on water and both permeates demonstrated better ratios compared to whey-based samples, making them more preferable for maintaining a healthy inflammatory response.

Kurut drink based on sweet whey exhibited higher levels of mono- and polyunsaturated fatty acids. These fatty acids are known to contribute to heart health, making this drink potentially useful for niche products aimed at enhancing cardiovascular health (Djuricic & Calder, 2021).

3.3. Amino acid profile

The amino acid profiles (μmol/L) of five different samples of the Kurut drink is presented in Table 3. Aspartic acid was found in higher amounts in K-AW and K-SW, at 0.52 μmol/L and 0.51 μmol/L respectively, compared to the other samples ($p \leq 0.05$). For glutamic acid, most samples showed uniform levels, except for K-AWP, where a slight decrease to 1.09 μmol/L was noted compared to 1.23 μmol/L in K-AW and K-SW, although these differences were not statistically significant ($p > 0.05$). Serine showed increased levels in K-AW and K-SW (0.31 μmol/L) compared to the levels in K-W and K-AWP (0.28 μmol/L, $p \leq 0.05$). Alanine reached 0.20 μmol/L in K-AW and K-SW, which was significantly higher than the 0.17 μmol/L in K-W ($p \leq 0.05$). Methionine, phenylalanine, and leucine in K-SW showed higher levels compared to K-W ($p \leq 0.05$), highlighting the positive impact of whey on the content of these amino acids. Lysine showed improvement in K-AW compared to K-W, with $p \leq 0.05$. Levels of tyrosine, cysteine, proline, valine, threonine, arginine, histidine and glycine were similar across all samples, with minor differences ($p > 0.05$).

The use of whey in Kurut drinks significantly improved the levels of important amino acids such as aspartic acid, alanine, methionine, phenylalanine, isoleucine, and leucine.

Our findings on the nutritional enhancement provided by whey are supported by Sharma (2019) and Yiğit et al. (2023), highlighting how whey protein improves the amino acid profiles of functional products and enhances their overall nutritional value. It has been stated that whey protein has an exceptional biological value, referring to how well and how quickly the body can utilize the protein consumed, exceeding that of egg, the former benchmark, by about 15%. In this regard, whey protein excels and is the protein of choice for bodybuilders, elite athletes, and those whose health is compromised. Additionally, whey-based drinks, particularly those made from sweet whey, appear to have higher concentrations of essential and branched-chain amino acids (Devries & Phillips, 2015; Smithers, 2008). The branched-chain amino acids (BCAAs) include leucine, isoleucine, and valine, and they play crucial roles in metabolism, blood glucose homeostasis, and neural function (Joy et al., 2013). Leucine, in particular, is known to be a key regulator of skeletal muscle protein synthesis (Rieu et al., 2007). Leucine activates the mTOR signaling pathway, which is a central controller of muscle protein synthesis, promoting the growth and repair of muscle tissue. Another essential amino acid, cysteine, is the building block of glutathione, a vital dietary antioxidant (Micke et al., 2002). Cysteine is crucial for fighting oxidative stressors and preventing redox imbalance-caused diseases (Trachootham et al., 2008). Glutathione, with its potent antioxidant properties, helps neutralize free radicals and reactive oxygen species, protecting cells from oxidative damage. This enhancement makes the drinks more nutritious and potentially beneficial for consumers seeking a well-rounded source of essential nutrients, thereby helping to fill the micronutrient gap in developing countries (World Food Programme, 2023).

3.4. Physicochemical profile

3.4.1. Color profile

Table 4 presents the CIELAB color profile of the Kurut samples. L^* values ranged from 45.94 (K-W) to 48.24 (K-SW), with all samples falling within a similar lightness range ($p > 0.05$). Red-green hue (a^* parameter) varied between 0.22 (K-AW) and 0.36 (K-AWP), with all samples showing statistically insignificant differences ($p > 0.05$). Yellow-blue hue (b^*) values ranged from 5.23 (K-W) to 8.52 (K-SWP). K-SWP, K-SW, and K-AW showed significantly higher b^* values than K-W ($p \leq 0.05$), indicating a greater yellow hue in these samples compared to K-W. Chroma (c^*) values indicating variations in color saturation across the different samples, showed a similar trend to b* values. K-SWP had the highest chroma (c^*, 8.52 ± 0.24), while K-W had the lowest (5.23 ± 0.09; $p \leq 0.05$). No significant differences were observed in h^* (hue angle) among samples.

It has been reported that the color and appearance of the Kurut samples without added color masking ingredients were similar to that of the original sweet or acid whey (Legarova & Lenka, 2010). The opaque white color, creamy consistency, and higher total solids content of the Kurut powder likely helped mask the typical yellowish-green color and whey off-flavors that can be associated with whey-based products (Mileriene, Serniene, Kondrotiene, et al., 2021).

We observed no significant color differences during storage of Kurut drinks (Table 5). The samples were pasteurized and packed in airtight tubes, then stored at refrigeration temperature in darkness. These factors likely minimized color degradation in the samples (Rizzolo & Cortellino, 2017).

3.4.2. Ph

Five Kurut drink samples were compared for their pH values during refrigerated storage (Table 6). Initially, both acid and sweet whey-based samples contained higher acidity levels compared to water-based Kurut drink (3.95; $p \leq 0.05$). Among the whey-based samples, acid whey-based samples exhibited lower pH compared to sweet whey-based samples, with K-AW demonstrating the lowest pH (3.15), suggesting the most acidic profile.

At Day 90, the mean pH of the Kurut drink samples exhibited notable changes. For sample K-W, the pH decreased to 3.70 ± 0.01, indicating a slight increase in acidity compared to Day 1. In contrast, all whey-based samples showed an increase in pH ($p \leq 0.05$), suggesting a reduction in acidity relative to its initial measurement. Sweet whey-based samples achieved the highest pH among all samples and maintained the least acidic environment at this stage.

By Day 180, no significant changes were observed in the pH levels of the Kurut drinks, with all samples remained stable, demonstrating consistent acidity throughout the storage duration. In terms of less acidic samples, K-SW and K-SWP (4.03 ± 0.01; 4.52 ± 0.01, respectively) reflected stability in their high pH profile, while K-W maintained a low pH of 3.60 ± 0.01, suggesting it retained low acidity throughout the entire storage period. Acid whey-based drinks demonstrated curvilinear changes in pH, initially starting low, increasing in the middle of storage, and then dropping again. In contrast, sweet whey drinks exhibited an increase in acidity over time, while water-based drinks showed a decreasing trend in pH throughout the storage period ($p \leq 0.05$).

3.5. Microbiological profile

Microbiological analysis of Kurut drinks showed low bacterial activity, with the numbers of lactic acid bacteria, enterobacteria, coliforms, yeasts, and molds falling below the detection level. Total aerobic bacterial counts did not reach the 10 CFU/ml threshold during the 180-day period in samples K-W and K-AW, while they were slightly higher in sample K-SWP. Despite the increase in bacterial counts observed on Day 180 compared to Day 1 and Day 90 (Table 7) in all samples except K-SWP, overall, Kurut drinks met the microbiological

Table 4
CIELAB color results in Kurut drinks.

	K-W	K-AW	K-AWP	K-SW	K-SWP
L*	45.94 ± 1.04[a]	45.95 ± 1.03[a]	46.30 ± 1.31[a]	48.24 ± 0.89[a]	46.86 ± 0.23[a]
a*	0.31 ± 0.05[a]	0.22 ± 0.03[a]	0.36 ± 0.14[a]	0.22 ± 0.06[a]	0.30 ± 0.05[a]
b*	5.23 ± 0.08[a]	6.64 ± 0.08[b]	5.72 ± 0.10[c]	7.26 ± 0.08[d]	8.52 ± 0.24[e]
c*	5.23 ± 0.09[a]	6.64 ± 0.08[b]	5.73 ± 0.11[c]	7.27 ± 0.08[d]	8.52 ± 0.24[e]
h*	87.30 ± 1.60[a]	88.65 ± 1.01[a]	86.79 ± 1.86[a]	88.27 ± 0.43[a]	88.53 ± 0.19[a]

*Different superscript letters indicate statistically significant difference among samples ($p \leq 0.05$). Differences among the samples in the b^* and c^* parameters highlight variations in the yellow-blue hue and color saturation.

Table 5
Color differences (ΔE) of Kurut drinks during refrigerated storage.

	K-W	K-AW	K-AWP	K-SW	K-SWP
Day 90	3.51 ± 0.51	3.20 ± 0.82	3.32 ± 0.7	3.31 ± 1.07	2.74 ± 1.97
Day 180	3.36 ± 0.18	3.70 ± 0.75	2.77 ± 1.06	3.16 ± 1.19	3.41 ± 2.09

Table 6
pH of Kurut drinks during refrigerated storage.

pH	K-W	K-AW	K-AWP	K-SW	K-SWP
Day 1	3.95 ± 0.10^{Aa}	3.15 ± 0.04^{Ab}	3.54 ± 0.03^{Ac}	3.60 ± 0.15^{Ac}	3.70 ± 0.18^{Ac}
Day 90	3.70 ± 0.01^{Ba}	3.95 ± 0.01^{Bb}	3.84 ± 0.01^{Bc}	4.11 ± 0.01^{Bd}	4.63 ± 0.01^{Be}
Day 180	3.60 ± 0.01^{Ba}	3.86 ± 0.01^{Cb}	3.74 ± 0.01^{Cc}	4.03 ± 0.01^{Bd}	4.52 ± 0.01^{Be}

Values labelled with different uppercase letters within the same column indicate significant ($p \leq 0.05$) differences between days; values labelled with different lowercase letters within the same row indicate significant ($p \leq 0.05$) differences between samples.

Table 7
Total aerobic bacterial count in Kurut drinks during refrigerated storage.

Days	Total aerobic bacteria, CFU/ml				
	K-W	K-AW	K-AWP	K-SW	K-SWP
1	<DL	0.30 ± 0.00^{Aa}	0.30 ± 0.00^{Aa}	<DL	1.25 ± 0.05^{Ab}
90	0.48 ± 0.00^{Aa}	0.30 ± 0.00^{Ab}	1.04 ± 0.40^{Bc}	<DL	1.14 ± 0.40^{ABd}
180	0.84 ± 0.06^{Ba}	0.85 ± 0.00^{Ba}	1.14 ± 0.06^{Bb}	1.08 ± 0.07^{c}	1.08 ± 0.07B^{c}

Values labelled with different uppercase letters within the same column indicate significant differences ($p \leq 0.05$) between days; values labelled with different lowercase letters within the same row indicate significant ($p \leq 0.05$) differences between samples. <DL – below detection limit.

requirements outlined in Commission Regulation (EC) No 2073/2005 (Official Journal of the European Union, 2005).

3.6. Sensory profile

Sensory profile results of Kurut drinks are shown in Table 8. The sensory profile of the traditional water-based Kurut drink (K-W) demonstrated a typical off-white color (8.70 ± 0.27) and an uneven consistency with a strong tendency to sediment, with the Kurut gradually separating from the liquid and settling at the bottom of the packaging (8.26 ± 0.81). The product is known for its notable sour aroma (7.90 ± 1.56) and sour flavor (7.86 ± 1.06), with a minimal touch of sweet smell (2.04 ± 0.86) and taste (0.90 ± 0.65). Initially, it shows a slight presence of whey flavor (1.10 ± 1.24) and has a lingering and prominent aftertaste (8.30 ± 0.76). It is loved by local consumers, and the overall acceptability of the drink was rated 9.0 ± 1.0, suggesting a high level of satisfaction among the evaluators.

In our study, replacing water with whey did not influence the whiteness (7.60–8.70) and consistency (7.88–8.26) attributes in samples ($p > 0.05$). All whey-based drinks demonstrated a stronger whey taste compared to the water-based one. However, in drinks made from permeates, especially from acid whey permeate, the whey taste was not as prominent ($p \leq 0.05$).

As anticipated, sweet whey (K-SW) and sweet whey permeate-based drinks (K-SWP) had a less prominent sour smell (4.94 and 5.30) and a more pronounced sweet smell (5.0 and 4.42) and taste (5.64 and 4.50) compared to other samples ($p \leq 0.05$). Additionally, sweet whey-based Kurut (K-SW) had the lowest aftertaste (4.50) compared to the rest of the samples (8.30–7.80; $p \leq 0.05$). However, for Kurut drinks enriched with sweet whey, we observed lower sensory acceptance, particularly due to their unexpected sweetness. As noted by Norton et al. (2021), this variation in perception is influenced by cultural and regional differences in consumer preferences, which significantly affects the acceptability of

Table 8
Sensory profile of Kurut drinks.

Descriptive, units	K-W	K-AW	K-AWP	K-SW	K-SWP
Whiteness	8.70 ± 0.27 [a]	8.36 ± 0.42 [a]	8.50 ± 0.74 [a]	7.60 ± 1.56 [a]	7.90 ± 0.65 [a]
Consistency	8.26 ± 0.81 [a]	7.98 ± 0.60 [a]	8.06 ± 1.14 [a]	7.88 ± 1.01 [a]	8.02 ± 0.79 [a]
Sour smell	7.90 ± 1.56 [a]	7.70 ± 1.35 [a]	7.60 ± 1.29 [a]	4.94 ± 1.11 [b]	5.30 ± 1.20 [b]
Sweet smell	2.04 ± 0.86 [a]	1.40 ± 0.96 [a]	2.0 ± 1.17 [a]	5.0 ± 2.15 [b]	4.42 ± 0.78 [b]
Sour taste	7.86 ± 1.06 [a]	8.56 ± 1.24 [a]	8.10 ± 0.96 [a]	3.10 ± 1.85 [b]	4.64 ± 0.88 [b]
Sweet taste	0.90 ± 0.65 [a]	0.96 ± 0.62 [a]	0.72 ± 0.61 [a]	5.64 ± 1.06 [b]	4.50 ± 0.50 [b]
Salinity	6.51 ± 0.81 [a]	5.50 ± 0.96 [b]	5,89 ± 0.76 [b]	3.74 ± 1.61 [c]	4.01 ± 1.10 [c]
Whey taste	1.10 ± 1.24 [a]	6.56 ± 0.94 [b]	1.50 ± 0.94 [a]	6.5 ± 0.79 [b]	3.70 ± 1.04 [c]
Aftertaste	8.30 ± 0.76 [a]	7.20 ± 0.57 [a]	7.80 ± 1.10 [a]	4.50 ± 0.79 [b]	7.50 ± 0.79 [a]

*Different superscript letters indicate statistically significant difference between samples ($p \leq 0.05$).

whey nutrients. High whey protein drinks also often face sensory challenges due to undesirable flavors following consumption. Researchers have found that both processing techniques and flavor-masking strategies can be useful in addressing these challenges in the manufacture of drinks containing a high content of whey protein (Mirzapour-Kouhdasht et al., 2023; Patel, 2015). Nevertheless, other experimental Kurut drinks made from whey were found to be as acceptable as traditional water-based counterpart.

Replacing water with sweet and acid whey influenced the perception of salinity in Kurut drinks. The highest mean salinity was detected in the water-based Kurut (K-W; 6.51 ± 0.81), while the lowest was found in the sweet whey-based Kurut (K-SW; 3.74 ± 1.61). The acid whey-based Kurut drinks (K-AW; 5.50 ± 0.96 and K-AWP; 5.89 ± 0.76) exhibited intermediate salinity levels, indicating they were less saline than K-W but more saline than K-SW. The presence of sour, and especially sweet whey, may mask some of the saltiness perceived in the drink, leading to a more balanced flavor profile compared to the water-based version, which may taste saltier due to its higher salinity level. This interaction can significantly influence consumer preference and overall liking of the Kurut drinks (Dziezak, 2016).

Fig. 2 presents the overall acceptability scores of Kurut drink samples evaluated over 180 days of refrigerated storage. The results indicate significant variations in consumer preference over time, highlighting the impact of storage duration on product quality. The initial acceptability (Day 1) of the sweet whey-based Kurut drink (K-SW) was notably lower (4.00 ± 1.46) compared to the other samples ($p \leq 0.05$), reflecting poor initial acceptability that may be attributed to its unusually sweet flavor profile or richer texture.

Over time, we observed changes in acceptability scores across the samples. Interestingly, K-SW showed improvement with a score of 7.83 ± 1.45, suggesting that its flavor developed positively over time, making it more appealing to consumers as it aged, while other samples maintained the same acceptability as on Day 1 ($p \leq 0.05$).

By Day 180, however, the water-based (K-W) and sweet whey-based (K-SW and K-SWP) Kurut drinks experienced a drastic drop in scores (2.33 ± 0.76; 0.15 ± 0.05; 0.90 ± 0.30, respectively), indicating very low consumer acceptance and potential spoilage or quality degradation over the storage period, suggesting they were no longer palatable. In contrast, the acid whey-based samples K-AWP and K-AW maintained relatively higher scores (7.25 ± 0.25; 6.35 ± 0.13, respectively), indicating that they remained acceptable to consumers even after extended storage. This resilience may be attributed to their acid-based formulation, which could have contributed to better preservation of sensory qualities.

4. Conclusions

Whey enhanced the amino acid profile of Kurut drinks, boosting essential nutrients and significantly improving their nutritional content. Drinks made from acid whey and sweet and acid whey permeates were found to be as acceptable as traditional water-based ones, supporting dairy industry efforts to reduce waste and enhance sustainability (O'Donoghue & Murphy, 2023). A Kurut drink based on sweet whey showed slightly lower overall acceptability due to its unexpected sweetness but offered higher levels of beneficial mono- and poly-unsaturated fatty acids. These fatty acids are known for promoting heart health, making the drink potentially valuable for niche products aimed at cardiovascular health improvement, especially appealing to consumers of functional foods prioritizing health benefits over flavor. This makes whey-enriched Kurut drinks a potent option for combating malnutrition in developing regions. Moreover, utilizing whey, a byproduct of cheese production, in Kurut drink production aligns with sustainable practices by reducing waste in the dairy industry. This not only supports environmental sustainability but also offers economic benefits by creating value-added products from what would otherwise be waste. The application of whey in enhancing the nutritional value of Kurut drinks could serve as a model for other traditional foods, suggesting broader implications for food formulation in the dairy industry. This is particularly important in developing countries like Kyrgyzstan, where nutritional deficiencies are prevalent and there is a need to provide micronutrient-rich food options (World Food Programme, 2024). Practical applications extend beyond nutritional enhancements, offering opportunities for the dairy industry to innovate while adhering to principles of sustainability and waste reduction (Pires et al., 2021).

During the shelf-life, some samples demonstrated acceptable levels of consumer preference initially and even improved over time, others exhibited rapid declines in acceptability, warranting further investigation into their formulations. To build on these findings, future research should focus on preservation techniques, storage-related chemical and microbial dynamics, and cultural preferences. Exploring nutrient bioavailability and expanding whey use in traditional foods could further enhance sustainability. This study is limited by absence of a comprehensive analysis of bioavailability and long-term health impacts, which future research should address to better understand the benefits of whey-enriched Kurut drinks.

CRediT authorship contribution statement

Askarbek Mametjanov: Writing – original draft, Investigation,

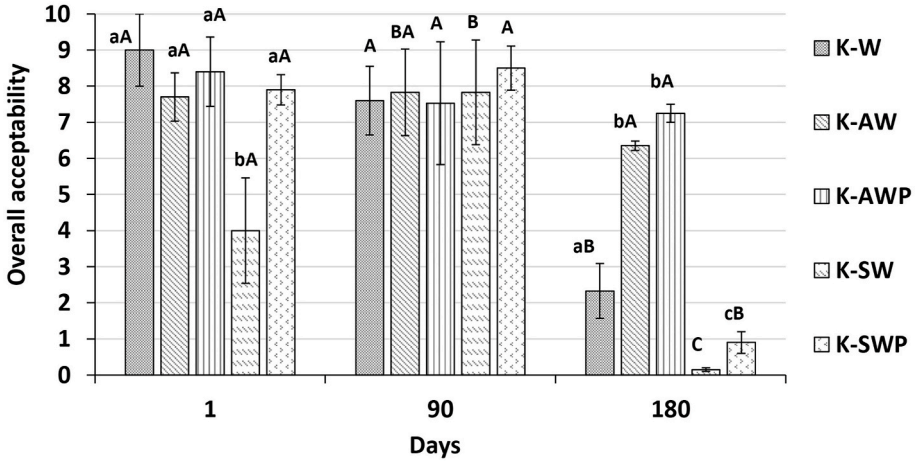

Fig. 2. Overall acceptability of Kurut drinks during 180 days of refrigerated storage. Means among storage days within the same sample treatment marked with different upper-case letters are significantly different ($p \leq 0.05$). Means between sample treatments within the same storage day marked with different lower-case letters are significantly different ($p \leq 0.05$).

Formal analysis, Data curation. **Mukarama Musulmanova:** Writing – review & editing, Funding acquisition, Formal analysis, Data curation. **Lina Laučienė:** Writing – review & editing, Formal analysis, Data curation. **Kristina Kondrotienė:** Writing – review & editing, Formal analysis, Data curation. **Elvidas Aleksandrovas:** Writing – review & editing. **Gintarė Zakarienė:** Writing – review & editing, Formal analysis, Data curation. **Sandra Kiseliovienė:** Writing – review & editing, Formal analysis, Data curation. **Alvija Šalaševičienė:** Writing – review & editing, Formal analysis, Data curation. **Milda Keršienė:** Writing – review & editing, Formal analysis, Data curation. **Daiva Leskauskaitė:** Writing – review & editing, Formal analysis, Data curation. **Loreta Šernienė:** Writing – review & editing, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Ethical statement

The sensory evaluation and consumer research in this study were conducted following ethical principles as approved by the Technological Institute of the Kyrgyz State Technical University Named after I. Razzakov. Ethical compliance for the research project titled *"Sustainable Innovations in Kurut Drink Production through Replacing Water with Dairy Whey to Improve Nutritional Quality*" was confirmed through the issuance of Certificate No. 2024–CCO-EBC-V-017 by the Sensory Evaluation Committee on 2024-09-10. All participants provided informed consent, and the study adhered to the appropriate protocols to protect their rights and privacy. Full disclosure of study requirements and risks was provided to participants, who were assured of their ability to withdraw at any time without coercion. No participant data were released without their knowledge or consent. As no vulnerable populations were involved, no additional permissions were necessary.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

This work was supported by funding of GIZ project "Vocational training for economic growth sectors in Central Asia" (No. 2023-PRO-000999; No. 81295537).

This project also received funding from the Research Council of Lithuania (LMTLT), agreement No: S-A-UEI-23-7.

Data availability

The data that has been used is confidential.

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