beverages

MDPI

Article

Physicochemical, Sensory, and Nutritional Quality Comparison of Natural-Flavored Drinkable Yogurts in Peruvian Highland Markets

Carmen R. Apaza-Humerez [1,*], Susy Yapu-Condori [1], Jheyson F. Tintaya-Mamani [1], Thalia A. Rivera-Ashqui [1] and Reynaldo J. Silva-Paz [2]

[1] Escuela Profesional de Ingeniería de Industrias Alimentarias, Facultad de Ingeniería y Arquitectura, Universidad Peruana Unión, Av. Villa Unión S/N, Ñaña, Lima 15461, Peru; susyy@upeu.edu.pe (S.Y.-C.); jheyson.tintaya@upeu.edu.pe (J.F.T.-M.); thaliarivera@upeu.edu.pe (T.A.R.-A.)

[2] Escuela Profesional de Ingeniería de Industrias Alimentarias, Departamento de Ingeniería, Universidad Nacional de Barranca, Av. Toribio de Luzuriaga N° 376, Mz. J-Urb. La Florida, Barranca 15169, Peru; rsilva@unab.edu.pe

* Correspondence: carmen271@upeu.edu.pe

Abstract

This study characterized the physicochemical, rheological, and sensory parameters of five commercial natural-flavored yogurt brands available in the Peruvian highland's region. The methodology included proximate composition, pH, titratable acidity, soluble solids, color (CIELab*), flow properties, viscoelastic behavior, and consumer sensory analysis using CATA questions and an acceptability test. The results revealed high variability among samples: soluble solids ranged from 7.24 to 16.27 °Brix, acidity from 0.68 to 1.03%, and two distinct rheological groups were identified: firm yogurts ($G' > 190$ Pa) and soft yogurts ($G' < 30$ Pa). Sensory attributes such as "pleasant texture," "creamy," and "milky flavor" positively influenced acceptability, whereas "acidic" and "watery" attributes negatively affected it. The sample with a balanced sensory profile (moderately sweet and creamy) achieved the highest acceptability score (7.8/9). It is concluded that yogurt quality in the highlands market is heterogeneous and that consumer acceptability depends more on sensory balance than on firmness alone. It is recommended that the dairy industry standardize fermentation processes to control acidity and optimize texture, prioritizing creaminess and homogeneity, and that regulatory authorities strengthen monitoring of these critical parameters to ensure safe and consistent products.

Keywords: yogurt; sensory analysis; Peruvian highlands; viscosity; consumer perception; quality

Check for updates

Academic Editor: Alessandra Del Caro

Received: 1 March 2026
Revised: 6 May 2026
Accepted: 7 May 2026
Published: 21 May 2026

Copyright: © 2026 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license.

1. Introduction

Yogurt is a semi-solid fermented dairy product obtained through milk acidification by the symbiotic action of lactic acid bacteria, primarily *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *Bulgaricus* [1]. This fermentation process not only imparts its characteristic texture and acidic flavor but also transforms yogurt into a functional food of high nutritional value, rich in high-quality proteins, calcium, B-complex vitamins, and probiotic microorganisms associated with digestive and immunological health benefits [2]. For these reasons, yogurt consumption has steadily increased worldwide and constitutes an essential component of the diet in many cultures, including Peru.

In the Peruvian context, the consumption of dairy products—particularly yogurt—has significantly increased over the past decade, driven by growing awareness of its nutritional benefits and an expanding commercial supply [3]. However, Peru's extraordinary geographical and climatic diversity poses unique challenges to the food industry. The Peruvian highlands, an Andean plateau extending above 3800 m above sea level (m.a.s.l.), represent one such distinctive region. The environmental conditions of this area—characterized by reduced atmospheric pressure, lower water boiling point, high solar radiation, and extreme thermal fluctuations—may influence multiple stages of the dairy chain, from primary milk production to storage and distribution of the final product [4]. These environmental factors, combined with logistical constraints and potential differences in local manufacturing practices, support the hypothesis that dairy products commercialized in the highlands may exhibit distinctive characteristics compared to those distributed at sea level.

Yogurt quality, which determines consumer acceptance and regulatory compliance, is traditionally evaluated through two interrelated sets of parameters: physicochemical and sensory. Physicochemical parameters are objective and quantifiable indicators, among which acidity, pH, total solids, fat content, and viscosity are considered critical. In contrast, sensory attributes represent the subjective evaluation of the product through human perception (sight, smell, taste, and touch). These include color (whiteness, uniformity), appearance (smoothness, absence of lumps), aroma (milky, acidic), mouthfeel (creamy, thick, firm), and taste (sweet, sour, bitter, aftertaste). Sensory perception ultimately determines consumer preference and repeat purchase behavior [5,6]. Importantly, physicochemical and sensory parameters are not independent; for instance, higher titratable acidity directly correlates with increased sour taste perception, while higher total solids content is often associated with enhanced creaminess and overall acceptability [7,8].

Despite the importance of these quality parameters, scientific evidence regarding the specific characteristics of commercial yogurts available in the Peruvian highlands remains limited. Most published studies have focused on products analyzed at sea level or under standardized laboratory conditions that do not replicate high-altitude environmental factors. However, a growing body of research has examined artisanal yogurt production in high-altitude regions globally. Celik & Temiz [9] investigated the chemical, physical, microbiological, and volatile aroma profiles of 24 traditional yogurts collected from highland areas (above 1300 m.a.s.l.) in the Black Sea Region of Turkey, revealing that while compositional values of homemade yogurts were acceptable, microbiological quality presented significant concerns, including coliform and *Escherichia coli* contamination in several samples. Furthermore, Popović et al. [10] demonstrate that high-altitude environments harbor unique autochthonous lactic acid bacteria with potential technological applications. These studies confirm that high-altitude regions present distinctive conditions that influence yogurt quality. Nevertheless, none have specifically addressed the Peruvian highlands above 3800 m.a.s.l., nor have they systematically compared the physicochemical, rheological, and sensory parameters of commercial versus artisanal products available to local consumers. Most published studies have focused on products analyzed at sea level or under standardized laboratory conditions that do not replicate high-altitude environmental factors, although Greek-style yogurts have been investigated [11]. This knowledge gap represents a significant concern. For highland consumers, uncertainty exists regarding whether marketed products meet quality standards and provide the expected sensory experience. For the dairy industry, the absence of region-specific data limits the optimization of formulation, fermentation processes, and cold chain management under high-altitude conditions, potentially affecting shelf life and product acceptance. For regulatory authorities, such as the Peruvian General Directorate of Environmental Health (DIGESA, acronyms in Spanish), locally generated evidence is essential to strengthen food quality and safety

surveillance across all regions of the country. Therefore, this study aims to generate applied scientific knowledge relevant to the Peruvian context. Its primary objective is to evaluate the physicochemical and sensory parameters of different commercial natural-flavored yogurt brands available in the Peruvian highlands market.

2. Materials and Methods

2.1. Sample Selection and Collection

Five (5) commercial brands of natural yogurt were selected (three industrially processed products and two artisanal products), available in major supermarkets and local markets in the city of Puno (3825 m.a.s.l.), located in the Peruvian highlands. The selection was based on market share and product availability in the study area during the sampling period (June 2025). All samples corresponded to the category of plain whole yogurt (non-flavored, without fruit addition), with a manufacturing date not exceeding 5 days. Products were purchased in triplicate batches (n = 3 per brand), totaling 15 experimental units. Immediately after purchase, samples were transported to the laboratory in insulated portable coolers with ice packs (2–4 °C) and analyzed before the expiration date indicated on the label [12]. Label information for each product was recorded (Table 1).

Table 1. Sample information based on the labeling of each yogurt container.

Sample	Ingredients	Package Size
Sample A	Whole milk, sugar, lactic cultures: *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*.	1 L
Sample B	Reconstituted concentrated milk, raw milk, reconstituted milk powder, thickener (polydextrose, INS 1200), skim milk powder, stabilizers (hydroxypropylated starch (INS 1442) and pectin (INS 440)), zinc source (zinc sulfate), vitamins A and D, and lactic cultures: *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*.	1 L
Sample C	Fresh semi-skimmed milk, flavorings, sugar, lactic cultures: *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus* and permitted preservatives.	1 L
Sample D	Partially skimmed milk (raw and reconstituted), milk solids, maltodextrin, stabilizers (INS 1401, gelatin, and INS 440), yogurt cultures (*Lactobacillus delbrueckii* subsp. *bulgaricus* and *Streptococcus thermophilus*) and probiotic cultures (*Lacticaseibacillus rhamnosus*, *Bifidobacterium* spp., *Lactobacillus acidophilus*, and *Lacticaseibacillus paracasei*)	946 mL
Sample E	Pasteurized whole milk, sugar, lactic cultures: *Streptococcus thermophilus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, and permitted preservatives.	1 L

2.2. Proximate Composition and Physicochemical Analysis

Declared nutritional values (protein, fat, carbohydrates, calcium, and energy) were transcribed directly from the nutrition labels and expressed per 100 g of product, in accordance with Peruvian labeling regulations [13]. The following physicochemical parameters were determined: Total Soluble Solids (TSS, °Brix): Measured at 20 °C using a digital refractometer (Atago PAL-1, Tokyo, Japan) after gentle homogenization of the sample [14]. pH: Determined using a calibrated digital pH meter (Hanna Instruments HI 2211, Simleu Silvaniei, Romania) equipped with a penetration electrode, inserted directly into the yogurt sample [15]. Titratable Acidity: Expressed as percentage of lactic acid (% w/v). Ten grams of sample were weighed, diluted with 10 mL of distilled water, and titrated with 0.1 N

NaOH using 1% phenolphthalein (Merck KGaA, Darmstadt, Germany) as indicator until the first persistent pale pink color (≥30 s) appeared [13]. Acidity was calculated as follows: % Lactic Acid = (mL NaOH × 0.1 × 0.009) × 100/Sample weight (g).

2.3. Rheological Properties

Rheological measurements were performed using a rotational rheometer with concentric cylinder geometry (Anton Paar MCR 92, Graz, Austria). All measurements were conducted at 20 °C (±0.1 °C) [16]. Flow Curve (Apparent Viscosity): a shear rate sweep from 0.1 to 100 s^{-1} was applied, recording shear stress values. Data were fitted to the Power Law (Ostwald–de Waele) model to determine the flow behavior index (n) and consistency index (K) [17]. Viscoelastic Properties: the Linear Viscoelastic Region (LVR) was first determined through amplitude sweep tests. Subsequently, frequency sweep tests were conducted from 0.1 to 100 rad·s^{-1} at a constant strain within the LVR (0.1%) to determine storage modulus (G′), loss modulus (G″), and loss tangent (tan δ) as a function of frequency [18].

2.4. Colorimetric Parameters

Color was measured in the CIE Lab* color space using a portable colorimeter (Konica Minolta CR-400, Tokio, Japan) with D65 illuminant and 10° standard observer angle. The instrument was calibrated with a standard white reference plate (L* = 97.10, a* = −0.13, b* = +1.88). Measurements were performed in triplicate for each sample placed in a glass cell. The recorded parameters were: L* (lightness; 0 = black, 100 = white), a* (red-green coordinate; +a = red, −a = green), b* (yellow-blue coordinate; +b = yellow, −b = blue) [19].

2.5. Sensory Analysis

Sensory evaluation was conducted in individual booths under controlled white lighting conditions, following ISO 8589:2007 guidelines [20]. A total of 110 regular yogurt consumers (18–55 years old; 60% women), all residing in the Department of Puno, were recruited locally. Participants attended a preliminary familiarization session to understand the attributes and methodology. Prior to evaluation, all participants provided written informed consent. The study protocol was approved by the Research Ethics Committee of the Peruvian Union University (Approval Certificate No. 034-2025-CEINDALI-UPEU, 18 July 2025). For Check-All-That-Apply (CATA) analysis, consumers were presented with a list of 15 descriptive terms (e.g., white color, cream color, milky aroma, acidic aroma, sweet taste, sour taste, bitter taste, creamy texture, gelatinous texture, firm texture, sandy texture, glossy, smooth, whey separation, aftertaste), generated from exploratory testing and literature [21–23]. Each sample (coded with random three-digit numbers and presented in balanced order) was evaluated by selecting all applicable terms [24]. In addition, it was evaluated overall acceptability, were evaluated using a structured 9-point hedonic scale (1 = "Dislike extremely", 9 = "Like extremely") [25].

2.6. Statistical Analysis

The experimental design followed a completely randomized design (CRD). For physicochemical, rheological, and colorimetric data, one-way analysis of variance (ANOVA) was performed. When significant differences were detected ($p < 0.05$), Tukey's Honestly Significant Difference (HSD) test was applied. Assumptions of normality (Shapiro–Wilk test) and homoscedasticity (Levene's test) were verified. CATA data were analyzed based on the frequency of citation of each attribute per sample. Differences among samples for each term were evaluated using Cochran's Q test. Correspondence Analysis (CA) was performed to graphically represent the association between samples and sensory attributes. For acceptability data, one-way ANOVA and Principal Component Analysis (PCA) were conducted

considering individual consumer scores [26]. All statistical analyses were performed using R software (v4.3.1) with the SensoMineR package (v1.28) [27].

3. Results

3.1. Proximate Composition and Physicochemical Parameters

Regarding the declared nutritional composition, the results allow the identification of two main product groups (Table 2). Samples A and C exhibited higher energy content (100–102 kcal/100 mL) and carbohydrate levels (15–16 g/100 mL), suggesting formulations with greater total solids content, possibly through the addition of skim milk powder or sucrose [2]. In contrast, Samples D and E displayed a nutritional profile characteristic of "light" products, with lower energy values (59–61 kcal/100 mL) and reduced fat content (0.5–1.8 g/100 mL). Notably, Sample E, despite its minimal fat content, declared the highest protein concentration (4.5 g/100 mL), likely due to the incorporation of milk protein concentrates to compensate for the loss of body and texture associated with fat reduction [17]. It is worth highlighting that Sample C failed to declare fat content on its label, a non-compliance with Peruvian labeling regulations [13] that limits informed consumer choice.

Table 2. Information on the centesimal composition and physicochemical parameters of natural commercial yogurts.

Sample	Energy (Kcal/100 mL) *	Protein (g/100 mL) *	Carbohydrates (g/100 mL) *	Fat (g/100 mL) *	Calcium (g/100 mL) *	Ph	Soluble Solids (°Brix)	Acidity
Sample A	102	4	16	2.5	100	4.55 ± 0.01^{b}	16.27 ± 0.07^{a}	0.84 ± 0.01^{c}
Sample B	115	2.9	5.9	2.5	100	4.52 ± 0.01^{bc}	7.24 ± 0.07^{e}	0.93 ± 0.01^{b}
Sample C	100	3.5	15	n.d.	100	4.65 ± 0.02^{a}	12.34 ± 0.06^{c}	0.68 ± 0.02^{e}
Sample D	61	2.7	8	1.8	109	4.51 ± 0.02^{c}	9.93 ± 0.06^{d}	1.03 ± 0.02^{a}
Sample E	59	4.5	8.7	0.5	120	4.56 ± 0.02^{b}	14.23 ± 0.06^{b}	0.73 ± 0.01^{d}

* Data: information obtained from the packaging label; n.d.: no data; Different letters in the same column indicate significant differences ($p < 0.05$) according to Tukey's test.

Significant differences were observed among the measured physicochemical parameters (Table 2). The pH ranged from 4.51 (Sample D) to 4.65 (Sample C). All values fell within the typical range for yogurt (4.0–4.6), which is essential for ensuring microbiological safety and proper milk protein gelation [11]. The greatest variability was recorded in total soluble solids (°Brix), with values ranging from 7.24 °Brix (Sample B) to 16.27 °Brix (Sample A). This parameter directly correlates with total sugar content. The exceptionally high value observed for Sample A (16.27 °Brix) is consistent with its declared high carbohydrate content (16 g/100 mL) and confirms substantial sucrose addition [28]. As expected, titratable acidity exhibited an inverse relationship with pH. Sample D showed the highest acidity (1.03%) along with the lowest pH, indicating a more intense fermentation profile. In contrast, Sample C presented the lowest acidity (0.68%) and the highest pH.

3.2. Colorimetric Parameters and Rheological Properties

3.2.1. Colorimetric Parameters

The color coordinates in the CIEL*a*b* space showed a perceptible range among the samples (Table 3). Lightness (L) varied between 71.42 (Sample C) and 74.12 (Sample B), the latter being significantly lighter. Negative a value (between −1.53 and −0.80) confirmed the absence of reddish tones and the predominance of a greenish hue, characteristic of dairy products. The b* coordinate showed the greatest variation (5.81 to 8.38). Sample E exhibited the highest b* value (8.38), suggesting a more yellowish color, possibly related to its high protein content or to the presence of riboflavin at higher concentrations [29].

Table 3. Colorimetric (CIE L*a*b* space) and rheological parameters of natural commercial yogurts.

Sample	Colorimetric Parameters			Rheological Properties				
	L*	a*	b*	n	K (Pa·s^n)	G′ (Pa)	G″ (Pa)	Tan δ
Sample A	71.64 ± 0.24 ^{d}	−1.13 ± 0.03 ^{b}	7.18 ± 0.01 ^{b}	0.392 ± 0.02 ^{a}	6.656 ± 0.38 ^{a}	25.35 ± 2.10 ^{b}	15.48 ± 1.30 ^{b}	0.61 ± 0.04 ^{b}
Sample B	74.12 ± 0.23 ^{a}	−1.42 ± 0.02 ^{d}	5.81 ± 0.02 ^{e}	0.348 ± 0.03 ^{a}	3.729 ± 0.269 ^{bc}	11.40 ± 1.05 ^{c}	12.42 ± 1.10 ^{b}	1.00 ± 0.06 ^{a}
Sample C	71.42 ± 0.19 ^{d}	−1.18 ± 0.01 ^{c}	6.08 ± 0.01 ^{d}	0.394 ± 0.03 ^{a}	2.745 ± 0.191 ^{c}	10.32 ± 0.98 ^{c}	8.23 ± 0.75 ^{c}	0.80 ± 0.05 ^{b}
Sample D	73.44 ± 0.11 ^{b}	−1.53 ± 0.02 ^{e}	6.80 ± 0.01 ^{c}	0.261 ± 0.03 ^{b}	8.033 ± 0.937 ^{a}	236.23 ± 15.4 ^{a}	127.85 ± 9.8 ^{a}	0.54 ± 0.03 ^{c}
Sample E	72.20 ± 0.03 ^{c}	−0.80 ± 0.02 ^{a}	8.38 ± 0.02 ^{a}	0.2972 ± 0.01 ^{b}	4.791 ± 0.72 ^{b}	196.89 ± 12.1 ^{a}	88.60 ± 6.9 ^{a}	0.45 ± 0.03 ^{c}

Different letters within the same column indicate significant differences ($p < 0.05$) according to Tukey's test, the values of G′, G″ and Tan δ were taken at a frequency of 1 rad.s^{-1}.

3.2.2. Rheological Properties

The flow behavior index (n) was lower than 1 for all samples (0.261–0.394), confirming the typical pseudoplastic behavior of yogurt gels [18]. Samples D and E exhibited the lowest n values, indicating more pronounced pseudoplasticity. The consistency index (K) varied significantly from 2.745 Pa·s^n (Sample C) to 8.033 Pa·s^n (Sample D). Samples D and E exhibited the highest storage modulus (G′) values (236.23 Pa and 196.89 Pa, respectively), approximately one order of magnitude greater than Samples A, B, and C, revealing a substantially stronger protein network structure [17]. The loss tangent (tan δ) was significantly lower in Samples D and E (0.54 and 0.45, respectively), whereas Sample B exhibited tan δ ≈ 1, suggesting a balance between elastic and viscous properties characteristic of weaker gels.

Figure 1a shows that all samples displayed typical non-Newtonian pseudoplastic flow curves [30], with Samples D and E reaching significantly higher shear stress values (~40 MPa at 100 s^{-1}) compared to Samples A, B, and C (~10–12 MPa). Figure 1b illustrates that apparent viscosity decreased sharply with increasing shear rate for all samples. Figure 1c shows that G′ remained greater than G″ across the evaluated frequency range for all samples, confirming solid-like gel behavior. However, for Samples D and E, both moduli exhibited only slight frequency dependence, characteristic of well-structured gels, whereas Samples B and C displayed weaker structures with greater viscous contribution [28]. Figure 1d shows that for Samples D and E, tan δ remained low (<0.5) and constant, whereas Sample B exhibited tan δ > 1 at low frequencies, indicating a high tendency toward syneresis [18].

3.3. Sensory Profile and Overall Liking

The sensory profile obtained using the CATA technique (Table 4) revealed that Sample C was perceived as the sweetest, correlating with its high soluble solids content. Samples B and D were strongly associated with acidic taste, consistent with their high titratable acidity values. Sample A presented a balanced profile, associated with "milky flavor" and "creamy." Sample E stood out as the most viscous and thick, being the only sample strongly associated with "pleasant texture" [31]. Sample B was perceived as watery with unpleasant texture.

Figure 2a presents the correspondence analysis map explaining 94.36% of total variability, identifying three distinct sensory groups: Group 1 (Samples A and E) associated with pleasant texture, creamy, viscous, and milky flavor; Group 2 (Samples B and D) characterized as acidic and watery; and Group 3 (Sample C) correlated mainly with sweet and light. Figure 2b shows that positive attributes (sweet, pleasant texture, creamy, milky flavor) increased acceptability, whereas negative attributes (acidic, unpleasant texture, watery) reduced acceptability [25]. Figure 2c presents acceptability scores: Sample A (7.8), Sample E (7.1), Sample C (6.5), Sample B (4.2), and Sample D (3.8). Figure 2d shows that most consumers preferred products with characteristics similar to Sample A.

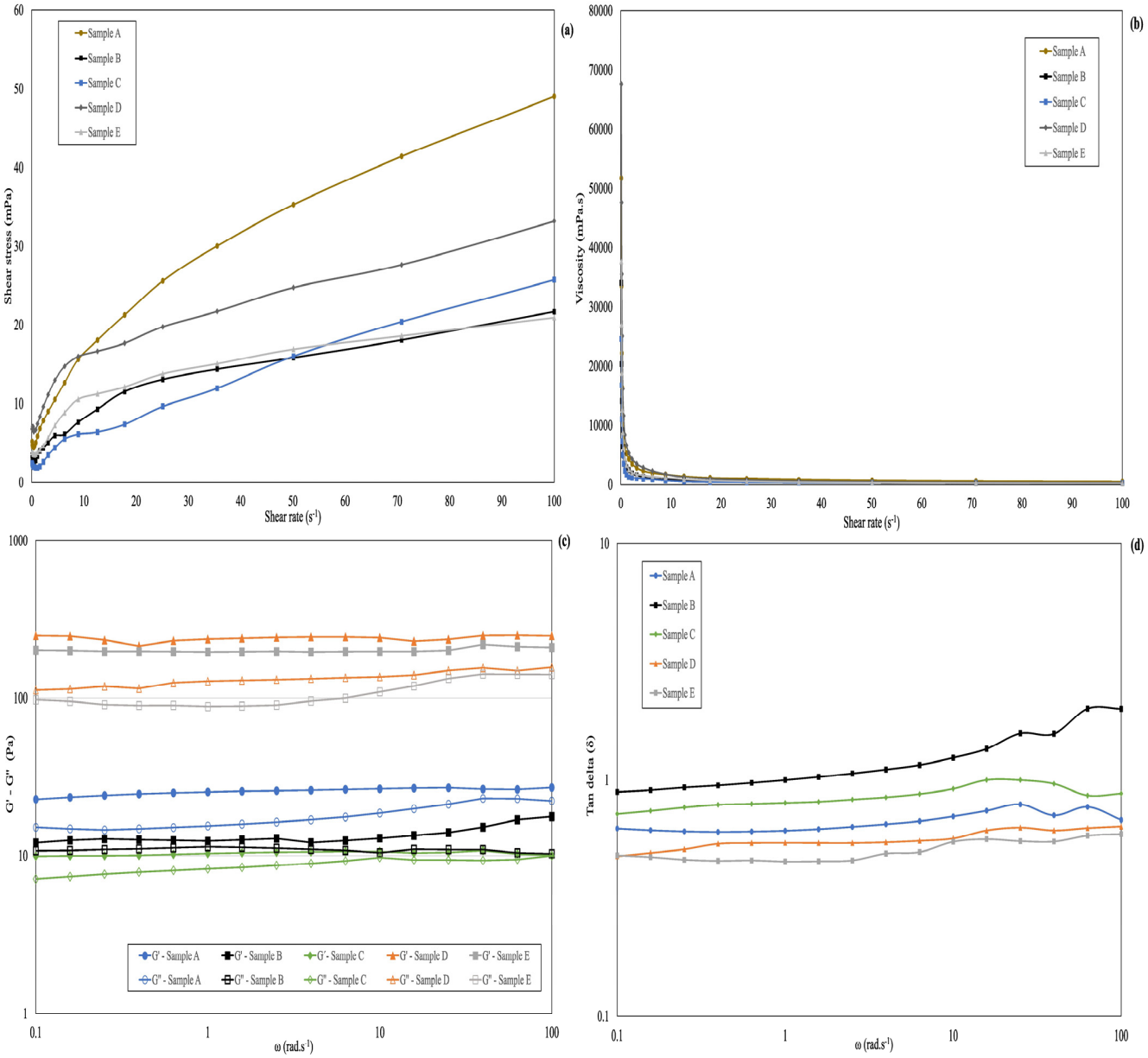

Figure 1. Rheological properties of commercial yogurts from the Peruvian highlands: (**a**) Flow curves (shear stress as a function of shear rate), (**b**) Apparent viscosity behavior as a function of shear rate, (**c**) Viscoelastic moduli (storage, G′, and loss, G″) as a function of angular frequency and (**d**) Evolution of tan delta (tan δ = G″/G′) as a function of angular frequency.

Table 4. Frequency of mention of sensory attributes (CATA) for yogurt samples.

Attributes	Valor-*p*	Sample A	Sample B	Sample C	Sample D	Sample E
Milky odor	0.468	0.245 ^{a}	0.218 ^{a}	0.209 ^{a}	0.164 ^{a}	0.255 ^{a}
Sweet	0.000	0.555 ^{b}	0.009 ^{d}	0.891 ^{a}	0.018 ^{d}	0.291 ^{c}
Acidic	0.000	0.255 ^{b}	0.736 ^{a}	0.055 ^{c}	0.827 ^{a}	0.245 ^{b}
Artificial flavor	0.141	0.164 ^{a}	0.227 ^{a}	0.282 ^{a}	0.245 ^{a}	0.173 ^{a}
Milk flavor	0.000	0.464 ^{a}	0.145 ^{c}	0.382 ^{a}	0.164 ^{bc}	0.309 ^{ab}
Viscous	0.002	0.127 ^{ab}	0.109 ^{ab}	0.091 ^{b}	0.100 ^{ab}	0.255 ^{a}
Creamy	0.000	0.455 ^{a}	0.082 ^{cd}	0.200 ^{bc}	0.018 ^{d}	0.345 ^{ab}
Watery	0.000	0.045 ^{c}	0.418 ^{ab}	0.273 ^{b}	0.591 ^{a}	0.055 ^{c}
Thick	0.000	0.345 ^{b}	0.145 ^{c}	0.127 ^{c}	0.082 ^{c}	0.555 ^{a}
Dense	0.136	0.136 ^{a}	0.109 ^{a}	0.082 ^{a}	0.109 ^{a}	0.182 ^{a}
Neutral	0.056	0.091 ^{a}	0.209 ^{a}	0.118 ^{a}	0.136 ^{a}	0.182 ^{a}

Table 4. *Cont.*

Attributes	Valor-*p*	Sample A	Sample B	Sample C	Sample D	Sample E
Light	0.000	0.218 ^{ab}	0.173 ^{abc}	0.245 ^{a}	0.091 ^{bc}	0.064 ^{c}
Fatty	0.089	0.027 ^{a}	0.091 ^{a}	0.073 ^{a}	0.064 ^{a}	0.118 ^{a}
Pleasant texture	0.000	0.591 ^{a}	0.136 ^{c}	0.445 ^{ab}	0.082 ^{c}	0.400 ^{b}
Unpleasant texture	0.000	0.073 ^{c}	0.345 ^{b}	0.164 ^{c}	0.500 ^{a}	0.191 ^{bc}

^{a,b,c,d} Different letters indicate significant differences ($p < 0.05$) according to the Cochran Q test using McNemar's test.

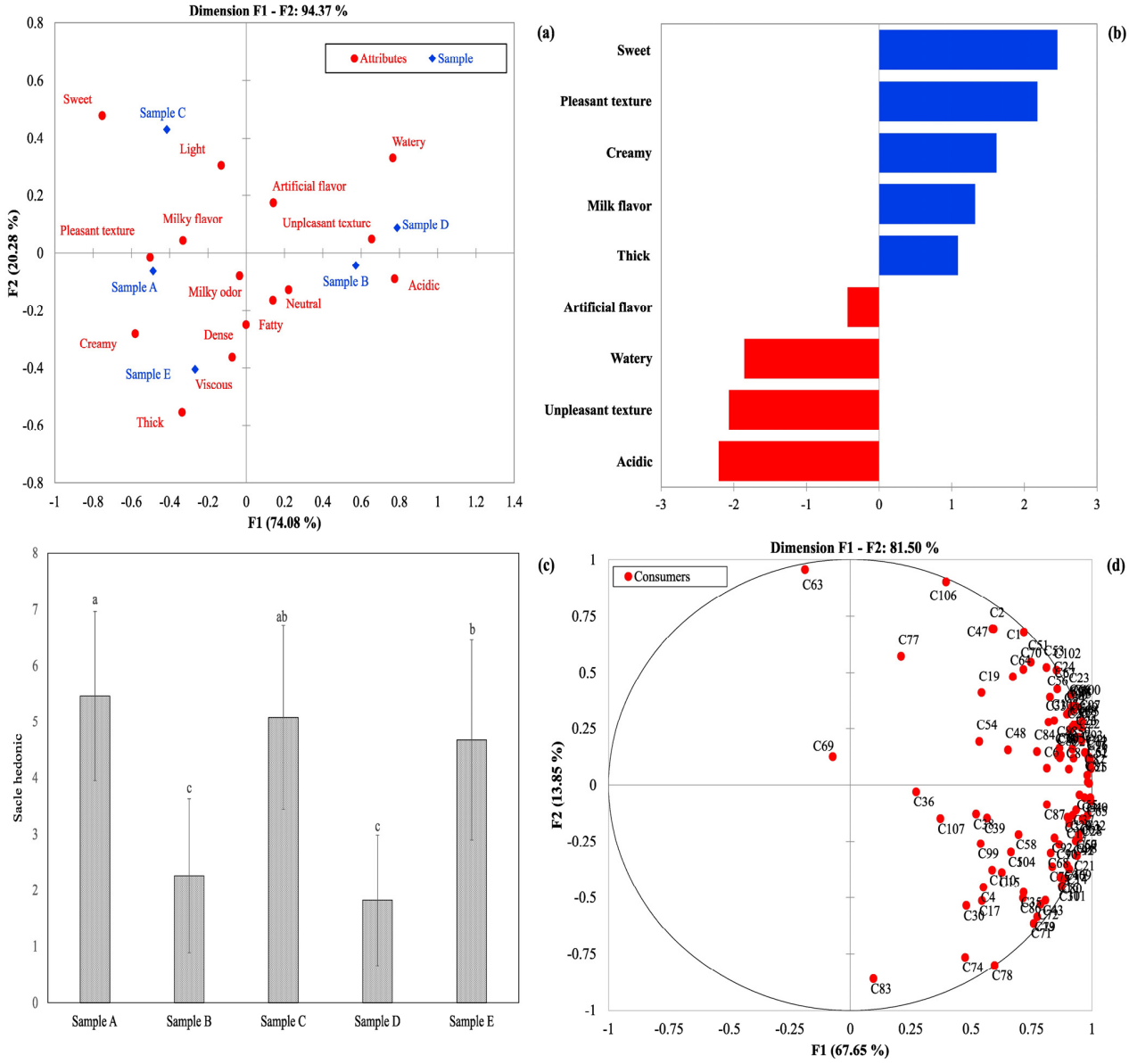

Figure 2. Sensory analysis of commercial yogurts from the Peruvian highlands: (**a**) Correspondence map (CATA) between samples and sensory attributes, (**b**) effect on the mean of the CATA attributes on overall acceptability, (**c**) Mean acceptability scores 9-point hedonic scale (^{a,b,c} Different letters indicate significant differences ($p < 0.05$) according to Tukey's test) and (**d**) Consumer sensory map regarding its acceptability.

4. Discussion

4.1. Proximate Composition and Physicochemical Parameters

The marked heterogeneity observed in composition and physicochemical parameters suggests a lack of production standardization for yogurts marketed in the highland region.

This variability may have direct implications for sensory quality and product consistency as perceived by consumers [12]. The significantly higher pH of Sample C (4.65) compared to other samples may be associated with a shorter fermentation time or the use of starter cultures with lower acidifying capacity. However, based on the ingredient information (Table 1), all samples declare the use of conventional yogurt starter cultures (Streptococcus thermophilus and Lactobacillus delbrueckii subsp. bulgaricus), without specification of strain composition or inoculum ratios. Therefore, differences in acidification cannot be conclusively attributed to microbial composition alone. The physicochemical characteristics of Sample C, including the use of semi-skimmed milk, added sugars, flavorings, and permitted preservatives, may also contribute to its higher pH and lower titratable acidity (0.68%) by influencing buffering capacity and fermentation dynamics. Likewise, variations in total solids—arising from differences in milk standardization and the presence or absence of stabilizers—may further modulate acid development and final pH. Consequently, the observed differences likely result from a combination of formulation and processing factors rather than solely from starter culture activity [16].

The high °Brix value of Sample A (16.27 °Brix) confirms substantial sucrose addition, a common strategy to enhance palatability and balance perceived acidity [28]. The low °Brix value of Sample B suggests a product with minimal or no added sugars. Sample D showed the highest acidity (1.03%) along with the lowest pH, indicating a more intense fermentation profile, likely enhanced by its more complex formulation including added milk solids and stabilizers, which can support microbial activity and acid production. Acidity not only determines the characteristic sour taste but also influences gel firmness and microbiological stability throughout shelf life [15]. However, these values are consistent with those reported with probiotic yogurt [32,33]. The potential influence of high-altitude environmental conditions—such as reduced atmospheric pressure and high solar radiation—on the stability of these parameters during transport and storage should be considered and warrants further investigation [19]. Overall, although commercial yogurts available in the Peruvian highlands comply with general regulatory ranges for the product category, they exhibit notably different compositional and acidity profiles. This reflects diverse formulation strategies aimed at different market segments but also underscores the need for stricter quality control to ensure product consistency, safety, and accurate labeling information for consumers in this region.

4.2. Colorimetric and Rheological Properties

The lower lightness of Samples A and C may be related to their higher total solids and carbohydrate contents (Table 2), which can affect the microstructure and light refraction [34]. The positive correlation between the b* value and the protein content of Sample E (4.5 g/100 mL) is consistent with findings linking higher protein content to increased yellowish tint due to riboflavin [29].

The rheological findings reveal two distinct product groups: a soft or semi-liquid yogurt group (Samples A, B, and C) characterized by low gel firmness ($G' < 30$ Pa), and a firm, well-structured yogurt group (Samples D and E) with high gel strength ($G' > 190$ Pa). This dichotomy is directly associated with product formulation. The markedly higher G' values in Samples D and E are consistent with their higher total solids content and, in the case of Sample E, its elevated protein content, which promotes increased crosslink density within the gel matrix [17]. The low tan δ values for Samples D and E confirm a more structured and stable gel network [28]. In contrast, Sample B exhibited tan $\delta \approx 1$ and tan $\delta > 1$ at low frequencies, indicating a balance between elastic and viscous properties characteristic of weaker or more fluid gels, with a high tendency toward syneresis (whey separation) during storage [18]. This behavior has critical implications for perceived mouthfeel and

storage stability, particularly under highland conditions where temperature fluctuations and transport-related mechanical stresses may more severely affect the structural integrity of weaker gels.

4.3. Sensory Profile and Overall Liking

The sensory results demonstrate that consumer acceptability is not determined by a single physicochemical parameter but rather by a complex balance of attributes. The positive association of sweet, pleasant texture, creamy, and milky flavor with higher acceptability scores confirms these as key drivers of liking, whereas acidic, watery, and unpleasant texture act as strong detractors [25,31]. The strong penalty associated with acidic taste may reflect a cultural preference for milder flavor profiles in the studied consumption context. The correspondence analysis map clearly validates the marked sensory heterogeneity in the market, confirming that consumer preferences are segmented according to contrasting flavor and texture profiles. The identification of three distinct groups (balanced/creamy, acidic/watery, and sweet/light) provides a framework for product positioning strategies. The preference of most consumers for products with characteristics similar to Sample A—an optimal balance between creaminess, milky flavor, moderate sweetness, and pleasant texture—provides clear guidance for product optimization aimed at the mass market of the Peruvian highlands. The higher sensory acceptability of Samples A and E is explained by their strong association with positive drivers, whereas the rejection of B and D is due to their strong linkage with detractors (acidic, watery). Sample E, despite its excellent rheological and textural profile, obtained slightly lower acceptability than Sample A, possibly because its extreme firmness may be less familiar or ideal for some consumers. Sample C, although very sweet, achieved only "slight liking," suggesting that excessive sweetness may be well received by a niche segment but is not optimal for the general population. The acceptability sensory map (Figure 2d) confirms that although preference heterogeneity exists, most consumers converge toward preferring a balanced product profile, providing robust evidence for product development strategies in this region.

5. Limitations

This study is geographically limited to Puno, which restricts its extrapolation to other high-altitude regions with different microclimates. The analysis included commercial brands and the most consumed artisanal products in the area. The sensory data reflect the preferences of local consumers (aged 18 to 55), which limits its generalizability to other populations. Despite these limitations, this study provides a solid foundation for future research. Therefore, further research incorporating other brands, production locations, and different seasons is recommended to fully elucidate the scope of these results.

6. Conclusions

The physicochemical, rheological, and sensory quality parameters of commercially available natural-flavored yogurts in the Peruvian highlands market show significant variability in composition, structure, and sensory properties, reflecting the existence of different formulation strategies and levels of quality control among manufacturers. From a physicochemical and structural standpoint, two main groups of products were identified: (a) yogurts with high firmness and gel structure (Samples D and E), characterized by high storage modulus values ($G' > 190$ Pa), high total solids, and, in one case (E), high protein content; and (b) yogurts with soft or semi-liquid consistency (Samples A, B, and C), with a weaker gel network ($G' < 30$ Pa). This dichotomy was directly linked to formulation, particularly total solids and protein content. In addition, a lack of standardization was observed in critical parameters such as titratable acidity (0.68–1.03%) and soluble solids

(7.24–16.27 °Brix), suggesting inconsistencies in fermentation and mixing processes. The sensory analysis revealed that these instrumental differences are perceived by consumers, and acceptability was determined by a complex balance of attributes. The main drivers of liking were pleasant texture, creaminess, and milky flavor, while the main detractors were acidic taste and watery texture. Consequently, Sample A, with a balanced profile (moderately sweet, creamy, and milky), achieved the highest hedonic acceptability. Sample E, despite its firm and elastic structure, was slightly less preferred, suggesting that extreme firmness may not be optimal. Samples B and D, associated with high acidity and watery/unpleasant texture, were rejected.

Author Contributions: Conceptualization, C.R.A.-H., S.Y.-C., J.F.T.-M., T.A.R.-A. and R.J.S.-P.; methodology, C.R.A.-H., S.Y.-C. and J.F.T.-M.; software, C.R.A.-H.; validation, S.Y.-C. and J.F.T.-M.; formal analysis, C.R.A.-H.; investigation, C.R.A.-H., S.Y.-C. and J.F.T.-M.; resources, C.R.A.-H. and S.Y.-C.; data curation, C.R.A.-H., S.Y.-C. and T.A.R.-A.; writing—original draft preparation, C.R.A.-H. and T.A.R.-A.; writing—review and editing, R.J.S.-P.; visualization, T.A.R.-A. and R.J.S.-P.; supervision, R.J.S.-P.; project administration, R.J.S.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding and the APC was funded by Universidad Peruana Union.

Institutional Review Board Statement: The research protocol was approved by the Research Ethics Committee of the Peruvian Union University (Certificate No. 034-2025-CEINDALI-UPEU, issued on 18 July 2025).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The original contributions presented in this study are included in the article. Further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Codex Alimentarius Commission (FAO/WHO). *Norma Para el Yogur (Yoghurt) y Productos Lácteos Fermentados Acidificados (CXS 243-2003)*; FAO: Rome, Italy, 2003. Available online: https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXS%2B243-2003%252FCXS_243s.pdf (accessed on 10 January 2026).
2. Sfakianakis, P.; Tzia, C. Conventional and innovative processing of milk for yogurt manufacture; development of texture and flavor: A review. *Foods* **2014**, *3*, 176–193. [CrossRef]
3. Sanchez-Matos, J.; Vázquez-Rowe, I.; Kahhat, R. Are Peruvians moving toward healthier diets with lower environmental burden? Household consumption trends for the period 2008–2021. *J. Ind. Ecol.* **2024**, *28*, 1147–1164. [CrossRef]
4. Barba, F.J.; Esteve, M.J.; Frígola, A. High pressure treatment effect on physicochemical and nutritional properties of fluid foods during storage: A review. *Compr. Rev. Food Sci. Food Saf.* **2012**, *11*, 307–322. [CrossRef]
5. Benatti, L.M.; Amorim, K.A.; Souza, A.H.S.; Passos, L.P.; Galdino, M.L.S.; Bresciani, L.F.V.; Rodrigues, J.F. Flavoring information influences sensory acceptance and purchase intention of yogurt: A study with text highlighting. *J. Sens. Stud.* **2025**, *40*, e70071. [CrossRef]
6. de Matos, A.D.; Hay, C.; Low, J.; Feng, J.; Lu, D.; Day, L.; Hort, J. Comparing liking and attitudes of Chinese immigrants in New Zealand towards drinkable yoghurt: An exploratory study. *Food Qual. Prefer.* **2021**, *94*, 104299. [CrossRef]
7. Gyawali, R.; Feng, X.; Chen, Y.P.; Lorenzo, J.M.; Ibrahim, S.A. A review of factors influencing the quality and sensory evaluation techniques applied to Greek yogurt. *J. Dairy Res.* **2022**, *89*, 213–219. [CrossRef]
8. da Cruz, A.G.; Ranadheera, C.S.; Nazzaro, F.; Mortazavian, A. (Eds.) *Dairy Foods: Processing, Quality, and Analytical Techniques*; Woodhead Publishing: Cambridge, UK, 2021.
9. Celik, O.F.; Temiz, H. Traditional yogurt dilemma; rich flavor vs. microbial safety: An investigation on Volatile Aroma Profiles, Chemical, and Microbiological Qualities of Traditional Yogurts. *J. Cent. Eur. Agric.* **2020**, *21*, 461–475. [CrossRef]
10. Popović, N.; Brdarić, E.; Đokić, J.; Dinić, M.; Veljović, K.; Golić, N.; Terzić-Vidojević, A. Yogurt produced by novel natural starter cultures improves gut epithelial barrier in vitro. *Microorganisms* **2020**, *8*, 1586. [CrossRef] [PubMed]

11. Pappa, E.C.; Kondyli, E.; Pappas, A.C.; Kyriakaki, P.; Zoidis, E.; Papalamprou, L.; Karageorgou, A.; Simitzis, P.; Goliomytis, M.; Tsiplakou, E.; et al. Physicochemical characteristics of commercially available Greek yoghurts. *Dairy* **2024**, *5*, 436–450. [CrossRef]
12. Terpiłowski, K.; Lange, I.; Kowalczyk, K.; Tomczyńska-Mleko, M.; Sapiga, V.; Wesołowska-Trojanowska, M.; Mleko, S.; Pérez-Huertas, S. Impact of storage conditions of yogurt dry ingredients on the physicochemical properties of the final product. *Appl. Sci.* **2023**, *13*, 13201. [CrossRef]
13. *NTP 202.092:2014*; Leche y Productos Lácteos. Leches Fermentadas. Yogur. Requisitos. Instituto Nacional de Defensa de la Competencia y de la Protección de la Propiedad Intelectual: Lima, Peru, 2014.
14. AOAC International. *Official Methods of Analysis of AOAC INTERNATIONAL*, 22nd ed.; AOAC International: Gaithersburg, MD, USA, 2023.
15. Du, H.; Yang, H.; Wang, X.; Zhu, F.; Tang, D.; Cheng, J.; Liu, X. Effects of mulberry pomace on physicochemical and textural properties of stirred-type flavored yogurt. *J. Dairy Sci.* **2021**, *104*, 12403–12414. [CrossRef] [PubMed]
16. Marlapati, L.; Basha, R.F.; Navarre, A.; Kinchla, A.J.; Nolden, A.A. Comparison of physical and compositional attributes between commercial plant-based and dairy yogurts. *Foods* **2024**, *13*, 984. [CrossRef]
17. García-Burgos, M.; Moreno-Fernández, J.; Alférez, M.J.; Díaz-Castro, J.; López-Aliaga, I. New perspectives in fermented dairy products and their health relevance. *J. Funct. Foods* **2020**, *72*, 104059. [CrossRef]
18. Ilić, N.; Belović, M.; Memiši, N.; Pestorić, M.; Škrobot, D.; Pezo, L.; Jevtić-Mučibabić, R.; Sanz, Y.; Brouzes, J. Rheological properties and sensory profile of yoghurt produced with novel combination of probiotic cultures. *Foods* **2024**, *13*, 3021. [CrossRef]
19. Pathare, P.B.; Opara, U.L.; Al-Said, F.A.J. Colour measurement and analysis in fresh and processed foods: A review. *Food Bioprocess Technol.* **2013**, *6*, 36–60. [CrossRef]
20. *ISO 8589:2007*; Sensory Analysis—General Guidance for the Design of Test Rooms. ISO: Geneva, Switzerland, 2007.
21. Clark, E.A.; Duncan, S.E.; Hamilton, L.M.; Bell, M.A.; Lahne, J.; Gallagher, D.L.; O'Keefe, S.F. Characterizing consumer emotional response to milk packaging guides packaging material selection. *Food Qual. Prefer.* **2021**, *87*, 103984. [CrossRef]
22. Jordán-Suárez, O.; Ramos-Ramírez, M.; Minaya-Agüero, P.; Tenorio-Domínguez, M.; Tuesta, T.; Silva-Paz, R.J. Efecto del diseño de la ficha para el análisis de yogurt bebible de fresa por el método CATA (check-all-that-apply). *Rev. UDCA Actual. Divulg. Cient.* **2024**, *27*, e2474. [CrossRef]
23. Dong, Y.; Sharma, C.; Mehta, A.; Torrico, D.D. Application of augmented reality in the sensory evaluation of yogurts. *Fermentation* **2021**, *7*, 147. [CrossRef]
24. Silva-Paz, R.J.; Avilés Pérez, H.A.; Rivera-Ashqui, T.A.; Apaza-Humerez, C.R. Comparison of rapid descriptive sensory methods applied to consumers in the evaluation of muffins. *Foods* **2025**, *14*, 2898. [CrossRef]
25. Stone, H.; Bleibaum, R.N. *Sensory Evaluation Practices*, 5th ed.; Academic Press: San Diego, CA, USA, 2020.
26. Meyners, M.; Castura, J.C.; Carr, B.T. Existing and new approaches for the analysis of CATA data. *Food Qual. Prefer.* **2013**, *30*, 309–319. [CrossRef]
27. R Core Team. *R: A Language and Environment for Statistical Computing*; R Foundation for Statistical Computing: Vienna, Austria, 2023. Available online: https://www.R-project.org/ (accessed on 20 November 2025).
28. Hoxha, R.; Evstatieva, Y.; Nikolova, D. Physicochemical, rheological, and sensory characteristics of yogurt fermented by lactic acid bacteria with probiotic potential and bioprotective properties. *Foods* **2023**, *12*, 2552. [CrossRef] [PubMed]
29. González-Tomás, L.; Costell, E. Relation between consumers' perceptions of color and texture of dairy desserts and instrumental measurements using a generalized procrustes analysis. *J. Dairy Sci.* **2006**, *89*, 4511–4519. [CrossRef]
30. Le Ba, T.; Dam, M.S.; Nguyen, L.L.P.; Baranyai, L.; Kaszab, T. A review of processing techniques and rheological properties of yogurts. *J. Texture Stud.* **2025**, *56*, e70006. [CrossRef]
31. Bolini, H.M.A.; Cardello, F.; de Medeiros, A.C.; Moskowitz, H. Unlocking consumer preferences: Sensory descriptors driving Greek yogurt acceptance and innovation. *Foods* **2025**, *14*, 130. [CrossRef] [PubMed]
32. Khalil, O.S.F.; Ismail, H.A.; Elkot, W.F. Physicochemical, functional and sensory properties of probiotic yoghurt flavored with white sapote fruit (*Casimiroa edulis*). *J. Food Sci. Technol.* **2022**, *59*, 3700–3710. [CrossRef]
33. Mehaya, F.M.; El-Shazly, A.I.; El-Dein, A.N.; Farid, M.A. Evaluation of nutritional and physicochemical characteristics of soy yogurt by Lactobacillus plantarum KU985432 and Saccharomyces boulardii CNCMI-745. *Sci. Rep.* **2023**, *13*, 13026. [CrossRef] [PubMed]
34. Halim, M.A.; Wazed, M.A.; Al Obaid, S.; Ansari, M.J.; Tahosin, A.; Rahman, M.T.; Khatun, A.A. Effect of storage on physicochemical properties, bioactive compounds and sensory attributes of drinks powder enriched with pumpkin (*Cucurbita moschata* L.). *J. Agric. Food Res.* **2024**, *18*, 101337. [CrossRef]

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.