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Physicochemical, Microbiological, and Rheological Characteristics of Fermented Sour Cream ("Suero Costeño") Produced in Colombia

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Abstract: "*Suero costeño*", a type of sour cream, is a traditional dairy product made mainly in the Colombian Caribbean region. In this study, we aim to characterize the physicochemical, microbiological, and rheological properties of *suero costeño* produced in Córdoba, Colombia. Samples of *suero costeño* were obtained from local producers, and physicochemical, microbiological, and rheologically (stationary tests) analyses were performed. A *suero costeño* was developed at a pilot scale and compared with that produced artisanally. The results showed great variability in the physicochemical characteristics of the *suero costeño* made by the different artisanal producers, with it being classified as either a full-fat sour cream or light sour cream, with values of protein (2–9%) and pH (3.5–5.8) similar to traditional dairy products from other countries. The *Suero costeño* samples showed an absence of *Salmonella* spp. and high counts of molds and yeasts, coliforms, *Escherichia coli*, and coagulase-positive *Staphylococcus aureus*, which is associated with the quality of the raw milk used and poor hygiene practices in the manufacturing process. *Suero costeño* can be classified as a pseudoplastic fluid, with some presenting thixotropy (19–93%), which may cause changes in the internal structure. Due to the great variability in its physicochemical, microbiological, and rheological characteristics, it is necessary to standardize the production process by applying good manufacturing practices to improve the marketing of this Colombian culinary product.

Keywords: fermented milk; artisanal product; pseudoplastic fluid; thixotropic

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1. Introduction

Fermented cream, also known as sour cream, is a kind of dairy product with a unique acidic flavor that is made by fermenting pasteurized cream using lactic acid bacteria (LAB) that can produce lactic acid [1,2]. Fermentation with LAB is a processing method that can extend shelf life and develop the characteristic flavor and texture of dairy products [3]. In addition, the lactic acid produced can inhibit the growth of pathogenic and spoilage microorganisms, contributing to the preservation of cultured dairy products [4,5]. Sour creams can be classified into four groups based on their fat content: Full-fat sour cream

(fat ≥ 18%), reduced fat sour cream (fat ≤ 13.5%), light sour cream (fat ≤ 9%), low-fat sour cream (fat ≤ 6%), and non-fat sour cream (fat ≤ 1%) [6–8].

Traditional sour cream is popular in some countries, including Mexico, North America, and Eastern Europe, because of its aromatic taste and creamy texture [7]. Several types of traditionally fermented cream are produced worldwide, such as *créme fraiche* in France, *crema espesa* in Mexico, *pomazánkové máslo* in the Czech Republic, traditional sour cream in Ukraine, and *suero costeño* in Colombia [9]. *Suero costeño* is an artisanal sour cream produced on the Northern Caribbean coast of Colombia, mostly in the rural population in the departments of Córdoba, Sucre, and Bolívar, and represents a gastronomic heritage of Colombian cuisine [10]. *Suero costeño* can be added to various foods, such as rice, stews, and sauces, and can also be used in dips, as a base in spreads on fried products, bread, and some cookies.

Suero costeño is usually obtained through the natural fermentation of raw cow's milk at room temperature (~30 °C), which is initiated through continuous reutilization of fermentation containers, such as calabash or plastic vessels, which contain indigenous microbial flora. During fermentation, a characteristic liquid–solid two-phase system is formed; the whey is removed, and the cream-like, thicker phase is mixed and salted [10,11]. The final product is an acidic, soured, and salty fermented milk with a creamy consistency [12]. The time required for obtaining *suero costeño* depends on the desired viscosity [10,13]. This procedure varies according to the area (municipalities or departments) where the *suero costeño* is made. It should be noted that the physicochemical and rheological characteristics depend on the type of raw materials used (whole milk or milk cream) and the processing method [14–16].

Suero costeño is an artisanal product made from raw milk, which significantly affects the microbial quality of the product. The quality and hygiene of raw milk can be compromised at any stage of the process, from production to marketing, harboring bacteria such as *Escherichia coli*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Salmonella* spp., *Campylobacter jejuni*, *Bacillus cereus*, and *Yersinia enterocolitica*, which are responsible for food poisoning and infections [10,13]. It is important to highlight that *suero costeño* has an optimal pH of 3.9, a condition that prevents the growth and survival of pathogenic microorganisms such as *Brucella* spp., *Mycobacterium bovis*, *Yersinia enterocolitica*, and *Bacillus cereus* [11,13]. On the other hand, the sodium chloride content of 2.34% in *suero costeño* acts as an inhibitory agent for some bacteria, such as *Campylobacter*, which dies at concentrations of 2% NaCl [17–19].

Several authors have reported poor hygienic–sanitary conditions in the elaboration of *suero costeño*, finding the presence of elevated numbers of enterobacteria, coliforms, and *staphylococci* [17,20]. In addition to microbiological problems, some sour creams, including *suero costeño*, present several quality defects, such as low viscosity and whey separation. To address these issues, food-grade hydrocolloids (mainly starches) or milk proteins have been added to cultured dairy products [7]. Standardization of the manufacturing process, by using pasteurized milk and commercial dairy cultures, would reduce the number of sanitary problems, but, unfortunately, this would lead to a reduction in the typical sensorial properties of *suero costeño* [11]. Furthermore, to standardize this process, it is necessary to know the physicochemical and rheological properties of this product.

Dairy rheology is important for dairy products' stability, process design, and quality control; it also provides information on product structure. The rheological behavior of milk products is complex and strongly dependent on the concentration and physical state of the dispersed phases. Milk and cream usually exhibit Newtonian behavior when products are fresh. The deviation from Newtonian behavior increases as fat and total solid contents increase [21–23].

Native, typical, or local foods are defined as those originating from a heritage or ethnic group and utilizing knowledge of local ingredients, plants, or animals [24]. These products have been historically consumed by populations who recognize their health benefits and are consolidated with knowledge transmitted from generation to generation [25]. Culinary knowledge constitutes an integral component of cultural and gastronomic heritage. However, its valuation, protection, and promotion can also contribute to the socio-economic development of producers and rural regions, as well as contributing to the promotion and positioning of larger-scale products in international markets [26]. Consequently, the determination of the quality and nutritional characteristics of native products, such as *suero costeño*, is a contribution to the valuation of traditional knowledge.

The objective of this study was to characterize the physicochemical, microbiological, and rheological properties of artisanal *suero costeño* produced in the department of Córdoba, Colombia. This characterization is important in order to understand the nutritional, hygienic, and sanitary quality and structural behavior of this food product. This is necessary to determine its shelf life and the adequate dimensioning of pumps, pipes, heat exchangers, agitation, and packaging operations, which are necessary in the standardization and industrial scaling of *suero costeño*.

2. Materials and Methods

2.1. Materials

Artisanal *suero costeño* was supplied by producers located in the department of Córdoba (Colombia), specifically in the municipalities of Ciénaga de Oro (9 artisanal producers), Cereté (5 artisanal producers), San Pelayo (4 artisanal producers), Chinú (4 artisanal producers), Sahagún (4 artisanal producers), Lorica (4 artisanal producers), and Montería (2 artisanal producers). The selection of these municipalities was predicated on two factors: first, their preeminence in the production of milk and dairy products within the department of Córdoba (Colombia), and second, the artisanal nature of their production methods and the volume of their output. The samples, corresponding to daily production, were collected in March 2023. They were transported to the laboratory in ice boxes, stored at 4 ± 1 °C, and processed immediately. The samples of *suero costeño* showed variation in their production process. The majority of producers (69%) include the fermentation stage of milk, fat, or both, while the rest use cheese whey, which is heated to precipitate the whey proteins, followed by liquefaction and the addition of salt. Figure 1 shows the *suero costeño* produced in the department of Córdoba (Colombia).



Figure 1. *Suero costeño* produced in the department of Córdoba, Colombia.

2.2. Proximate Composition

The physicochemical analysis of the *suero costeño* was determined according to the Official Methods of Analysis of AOAC International, the American Public Health Association (APHA), and the International Organization for Standardization (ISO). The samples were

analyzed to determine their protein content using the Kjeldahl method (AOAC 920.85), fat was analyzed using the Soxhlet method (AOAC 920.85), crude fiber was analyzed using dilute acid and alkali hydrolysis, incineration, and weight difference (AOAC 960.52), moisture content was analyzed based on the loss of mass of samples in an oven (FD56, Binder, Tuttlingen, Germany) heated at 102 ± 2 °C (AOAC 925.10), ash was determined gravimetrically for samples heated at 550 °C in a muffle furnace (AOAC 925.10), carbohydrates were analyzed based on difference (AOAC 931.02), chlorides were analyzed using titration with $AgNO_3$ (APHA 15.051), and pH was analyzed using potentiometry (AOAC 981.12).

2.3. Evaluation of the Microbiological Quality of Artisanal Suero Costeño

Since Colombian regulations lack microbiological parameters to evaluate the quality of *suero costeño*, we used the microbiological criteria established for fermented milk and spreadable acid whey (Resolution 1407 of 2022 of the Ministry of Health and Social Protection of Colombia). These criteria include molds and yeasts, coliforms, *Escherichia coli*, coagulase-positive *Staphylococcus aureus*, and *Salmonella* spp., following the methodology proposed by the APHA [27]. To verify the quality of raw milk used in *suero costeño* production, mesophile tests were performed, following the American Public Health Association (APHA) methodology and the Colombian Technical Standard NTC 4519.

2.4. Rheological Behavior of Suero Costeño

Rheological behavior was measured using the method described by Andrade et al. [28] with slight modifications. First, 100 mL of the *suero costeño* was taken and placed in a viscometer VL210003 (FungiLab, Madrid, Spain) with spindle L-4, varying the rotation speed of 1 to 100 rpm in ascending and then in descending form from 100 to 1 rpm. The maximum rotation speed (100 rpm) was maintained for two minutes. The test was performed at a temperature of 25 °C. The rheological behavior was determined using the Ostwald–de Waele or power law model (Equation (1)):

$$\eta_{app} = K\,\dot{\gamma}^{\,n-1} \tag{1}$$

where η_{app} is the apparent viscosity (Pa s), K is the consistency coefficient (Pa s^n), γ is the shear rate (s^{-1}), and n is the flow behavior index (dimensionless).

The shear rate was obtained based on the rotation speed (N, rpm), according to Equation (2):

$$\dot{\gamma} = 0.263\; n^{-0.771}\,\mathrm{N} \tag{2}$$

The thixotropic properties of *suero costeño* were determined from the area between the upward and downward curves (Equation (3)):

$$\text{Thixotropic, \%} = \frac{\int_{\dot{\gamma}_1}^{\dot{\gamma}_2} K_{asc}\,\dot{\gamma}^{\,n_{asc}} - \int_{\dot{\gamma}_1}^{\dot{\gamma}_2} K_{desc}\,\dot{\gamma}^{\,n_{desc}}}{\int_{\dot{\gamma}_1}^{\dot{\gamma}_2} K_{asc}\,\dot{\gamma}^{\,n_{asc}}}\;100\% \tag{3}$$

where K_{asc} and K_{desc} are the consistency coefficients upward and downward, respectively, and n_{asc} and n_{desc} are the flow behavior indices upward and downward, respectively.

2.5. Manufacture of the Pilot-Scale Prototype of Suero Costeño

Taking into account the conditions of the artisanal production process of Suero Costeño from the department of Córdoba (Colombia), a pilot production trial was carried out at the Dairy Products Quality Analysis Laboratory of the University of Córdoba (Colombia). Raw milk from the university's farm was used, its quality characteristics were measured (pH, acidity, and organoleptic characteristics), and the conditions for spontaneous fermentation

(room temperature, around 30 °C, and a fermentation time of 24 h) were allowed to occur in a 3-litre plastic container that had previously been sanitized. At the end of the fermentation time, the curds were separated from the whey, 1.5% salt was added, and the curds were homogenized in an industrial mixer. Physicochemical analyses (moisture, protein, fat, ash, fiber, chlorides, and pH) were determined in order to compare the quality of the product obtained with that produced by artisans.

2.6. Statistical Analysis

The Kolmogorov–Smirnov and Levene tests were carried out to determine the normality and homogeneity of the data obtained. If the data were homogeneous and normally distributed, one-way analysis of variance (ANOVA) and Tukey's test were performed using JMP Pro 17 software (SAS Institute, Cary, NC, USA) to compare significant differences between samples, with a significance level of 5%. Dunnett's test ($p < 0.05$) was used to establish the differences between the *suero costeño* obtained from local producers and the *suero costeño* produced at the pilot plant scale. All of the data are expressed as the mean ± standard deviation of triplicate determinations.

3. Results and Discussion

3.1. Physicochemical Analyses

Table 1 shows the values of the physicochemical parameters of the *suero costeño* produced in the department of Córdoba (Colombia). These values are similar to those reported for *suero costeño* produced in Montería [10] and in the department of Bolivar [29], commercial sour creams in the United States [16], *amasi* (sour milk from the Zulu people in South Africa) [30], and the Cretan sour cream Staka [9]. According to the fat content, the *suero costeño* evaluated can be classified into full-fat sour cream (fat ≥ 18%) and light sour cream (fat ≤ 9%). However, the ones produced in Montería and some of the Chinú (Ch2), Cereté (C3), and Sahagun (S1) ones can be considered as low-fat sour cream (fat ≤ 6%). This variability in fat content is due to the fact that in the production of *suero costeño*, some producers use whole milk as raw material, and others use cream, in addition to the amount of whey that is eliminated. Nevertheless, these values are lower than sour creams and fermented dairy products made in Balkan countries, which have fat content between 30 and 46%, and even *kajmak* contains about 60% fat, depending on the degree of whey removal [1,9,31].

Our ANOVA results show that there are significant differences between the physicochemical characteristics of the artisanal *suero costeño* produced by the different producers of the department of Córdoba, Colombia. The above differences are due to the raw materials used and the processing method. However, this artisanal product has several similarities with various traditional fermented dairy products from other continents that are made from cow's milk or small dairy animals (reindeer and mithum). Reindeer sour cream is obtained from milk fermented for a short time with lactic acid bacteria, and its nutritional composition is 10.60% fat, 6.50% protein, 15.10% carbohydrates, and 0.70% ash. Curd or cottage cheese is a non-liquid white fermented mithun milk product traditional to Eastern and Northern Europe. It is made by fermenting milk and the subsequent removal of whey; however, the final mixing that is applied to *suero costeño* is not carried out. Curd contains 8.9% fat and 6.5% protein [32]. These products have similar physicochemical properties (fat and protein) to the *suero costeño* produced in the municipalities of Cereté (C3, C4, and C5) and Chinú (Ch1 and Ch2). The high protein content present in the *suero costeño* from these municipalities may be due to the addition of whey protein during its production.

Table 1. Physicochemical characteristics of artisanal *suero costeño*.

Municipality	Artisanal Producer	Moisture, %	Protein, %	Fat, %	Ash, %	Crude Fiber, %	Carbohydrates, %	Chlorides	pH
Ciénaga de Oro	CO1	60.46 ± 1.92 ^{d}	3.39 ± 0.06 ^{c,d,e}	18.00 ± 0.00 ^{b}	7.66 ± 0.66 ^{a}	0.50 ± 0.00 ^{c,d}	6.50 ± 1.32 ^{d,e}	0.96 ± 0.01 ^{g}	4.86 ± 0.01 ^{d}
	CO2	61.47 ± 1.16 ^{d}	4.94 ± 0.21 ^{b,c,d}	12.00 ± 0.00 ^{c,d,e}	5.37 ± 1.31 ^{a,b}	0.21 ± 0.01 ^{g,h}	16.23 ± 0.06 ^{b,c,d}	0.99 ± 0.02 ^{g}	4.96 ± 0.00 ^{c}
	CO3	59.93 ± 8.48 ^{d,e}	7.66 ± 1.00 ^{a}	12.50 ± 0.71 ^{c,d,e}	7.33 ± 2.09 ^{a}	0.20 ± 0.01 ^{g,h}	12.59 ± 10.86 ^{c,d,e}	0.15 ± 0.00 ^{j}	4.91 ± 0.01 ^{c}
	CO4	76.45 ± 1.08 ^{a}	4.49 ± 0.35 ^{c,d}	9.00 ± 0.00 ^{d,e,f}	2.93 ± 1.97 ^{c,d,e}	0.52 ± 0.01 ^{c}	7.15 ± 2.71 ^{d,e}	0.84 ± 0.00 ^{g}	4.34 ± 0.00 ^{f}
	CO5	61.52 ± 0.76 ^{d}	3.76 ± 0.01 ^{d,e}	8.50 ± 0.71 ^{d,e,f}	1.29 ± 0.14 ^{d,e,f}	0.26 ± 0.01 ^{g}	24.94 ± 0.19 ^{a,b,c}	0.47 ± 0.04 ^{h}	4.06 ± 0.01 ^{h}
	CO6	63.03 ± 2.85 ^{c,d}	3.80 ± 0.04 ^{c,d,e}	28.00 ± 1.41 ^{a}	2.25 ± 0.04 ^{d,e,f}	0.60 ± 0.00 ^{b}	2.93 ± 1.44 ^{e}	1.09 ± 0.00 ^{f}	4.82 ± 0.02 ^{d}
	CO7	44.30 ± 0.18 ^{g}	3.77 ± 0.01 ^{c,d,e}	19.00 ± 4.24 ^{a,b}	4.77 ± 0.00 ^{b,c,d}	0.22 ± 0.01 ^{g}	28.17 ± 4.05 ^{a,b}	0.45 ± 0.00 ^{h}	3.36 ± 0.00 ^{l}
	CO8	54.16 ± 4.39 ^{e}	4.97 ± 0.35 ^{b,c,d}	8.00 ± 0.00 ^{d,e,f}	3.41 ± 0.81 ^{b,c,d}	0.74 ± 0.01 ^{a}	29.47 ± 5.55 ^{a}	0.26 ± 0.00 ^{i}	5.84 ± 0.01 ^{a}
	CO9	51.35 ± 0.89 ^{e,f}	2.94 ± 0.25 ^{d,e,f}	8.50 ± 0.71 ^{d,e,f}	2.41 ± 0.02 ^{c,d,e,f}	0.18 ± 0.00 ^{h}	34.81 ± 0.08 ^{a}	0.19 ± 0.00 ^{i}	5.08 ± 0.00 ^{b}
Cereté	C1	63.96 ± 1.22 ^{c,d}	5.64 ± 0.23 ^{b,c}	14.50 ± 0.71 ^{b,c,d}	3.23 ± 0.01 ^{b,c,d}	0.38 ± 0.00 ^{f}	12.68 ± 0.28 ^{c,d,e}	1.28 ± 0.00 ^{e}	5.04 ± 0.00 ^{b}
	C2	74.67 ± 0.30 ^{a}	4.83 ± 1.11 ^{b,c,d}	13.50 ± 0.71 ^{b,c,d}	3.36 ± 0.01 ^{b,c,d}	0.41 ± 0.00 ^{e}	3.65 ± 0.71 ^{e}	1.25 ± 0.00 ^{e,f}	5.57 ± 0.00 ^{a}
	C3	67.07 ± 0.83 ^{c}	4.25 ± 0.22 ^{c,d,e}	5.00 ± 0.00 ^{e,f}	5.01 ± 0.01 ^{a,b,c}	0.48 ± 0.00 ^{d}	18.68 ± 1.06 ^{b,c,d}	1.70 ± 0.00 ^{a}	3.54 ± 0.00 ^{k}
	C4	56.44 ± 0.78 ^{e}	4.59 ± 0.25 ^{c,d}	10.00 ± 0.00 ^{d,e,f}	4.78 ± 0.01 ^{b,c}	0.40 ± 0.00 ^{e,f}	24.20 ± 1.04 ^{a,b,c}	1.49 ± 0.00 ^{c}	4.63 ± 0.00 ^{e}
	C5	67.70 ± 2.12 ^{b,c}	7.39 ± 0.01 ^{a,b}	7.00 ± 1.41 ^{e,f}	5.39 ± 0.00 ^{a,b}	0.66 ± 0.00 ^{b}	12.53 ± 3.54 ^{c,d,e}	1.65 ± 0.00 ^{b}	4.10 ± 0.00 ^{g}
San Pelayo	SP1	74.58 ± 0.98 ^{a}	2.54 ± 0.11 ^{e,f}	9.50 ± 3.54 ^{d,e,f}	2.60 ± 0.00 ^{c,d,e,f}	0.52 ± 0.03 ^{c}	10.79 ± 2.45 ^{c,d,e}	1.48 ± 0.00 ^{c}	4.78 ± 0.00 ^{d}
	SP2	54.28 ± 1.67 ^{e}	4.63 ± 0.01 ^{c,d}	25.00 ± 0.00 ^{a}	2.61 ± 0.01 ^{c,d,e,f}	0.22 ± 0.00 ^{g}	13.49 ± 1.68 ^{c,d,e}	1.27 ± 0.00 ^{e}	3.51 ± 0.00 ^{k}
	SP3	48.85 ± 0.45 ^{f}	4.05 ± 0.99 ^{c,d,e}	14.00 ± 2.83 ^{b,c,d}	2.66 ± 0.02 ^{c,d,e,f}	0.11 ± 0.00 ^{i}	30.45 ± 3.34 ^{a}	1.44 ± 0.00 ^{d}	4.66 ± 0.00 ^{e}
	SP4	47.03 ± 0.72 ^{f}	3.66 ± 0.91 ^{d,e,f}	11.00 ± 4.24 ^{c,d,e,f}	3.05 ± 0.00 ^{b,c,d,e}	0.18 ± 0.01 ^{h}	35.27 ± 4.05 ^{a}	1.30 ± 0.00 ^{d,e}	4.45 ± 0.00 ^{e}
Chinú	Ch1	57.59 ± 4.01 ^{d,e}	8.74 ± 0.04 ^{a}	12.00 ± 1.41 ^{c,d,e}	0.05 ± 0.00 ^{f}	0.54 ± 0.00 ^{c}	21.63 ± 5.47 ^{a,b,c}	1.72 ± 0.00 ^{a}	3.93 ± 0.01 ^{h}
	Ch2	66.03 ± 2.04 ^{c}	6.53 ± 0.36 ^{a,b}	4.00 ± 0.00 ^{f}	3.25 ± 0.00 ^{b,c,d}	0.59 ± 0.01 ^{b}	20.20 ± 1.68 ^{a,b,c}	1.34 ± 0.01 ^{d}	3.73 ± 0.00 ^{j}
	Ch3	55.27 ± 0.64 ^{e}	7.74 ± 0.02 ^{a}	6.50 ± 0.71 ^{e,f}	2.39 ± 0.00 ^{d,e,f}	0.88 ± 0.00 ^{a}	28.11 ± 1.32 ^{a,b}	0.22 ± 0.01 ^{i}	3.73 ± 0.01 ^{j}
	Ch4	60.34 ± 2.87 ^{d}	4.39 ± 0.52 ^{c,d,e}	8.50 ± 0.71 ^{d,e,f}	2.80 ± 0.01 ^{c,d,e}	0.48 ± 0.00 ^{d}	23.97 ± 2.70 ^{a,b,c}	1.45 ± 0.00 ^{c,d}	4.65 ± 0.01 ^{e}
Sahagún	S1	76.04 ± 0.28 ^{a}	6.44 ± 0.02 ^{a,b}	2.50 ± 0.71 ^{f}	2.52 ± 0.00 ^{c,d,e,f}	0.32 ± 0.01 ^{f}	12.51 ± 0.97 ^{c,d,e}	1.23 ± 0.00 ^{f}	3.62 ± 0.05 ^{k}
	S2	59.47 ± 0.18 ^{d}	7.73 ± 0.12 ^{a}	15.00 ± 0.01 ^{b,c}	2.40 ± 0.00 ^{c,d,e,f}	0.89 ± 0.01 ^{a}	15.41 ± 0.30 ^{c,d,e}	1.55 ± 0.00 ^{b}	3.84 ± 0.00 ^{i}
	S3	66.68 ± 0.23 ^{c}	7.77 ± 0.40 ^{a}	16.50 ± 0.71 ^{b,c}	1.38 ± 0.01 ^{d,e,f}	0.33 ± 0.01 ^{f}	7.68 ± 1.36 ^{d,e}	1.70 ± 0.00 ^{a}	3.69 ± 0.01 ^{j}
	S4	56.19 ± 0.93 ^{e}	8.30 ± 0.11 ^{a}	9.00 ± 0.00 ^{d,e,f}	2.73 ± 0.00 ^{c,d,e,f}	0.44 ± 0.00 ^{e}	23.79 ± 0.83 ^{a,b,c}	1.43 ± 0.00 ^{d}	3.78 ± 0.01 ^{i}
Lorica	L1	76.25 ± 0.06 ^{a,b}	3.36 ± 0.01 ^{d,e,f}	15.00 ± 0.00 ^{b,c}	2.74 ± 0.00 ^{c,d,e}	0.64 ± 0.00 ^{b}	2.66 ± 0.07 ^{e}	0.19 ± 0.00 ^{i}	5.60 ± 0.00 ^{a}
	L2	66.42 ± 0.05 ^{c}	5.11 ± 0.63 ^{b,c,d}	15.00 ± 0.00 ^{b,c}	0.49 ± 0.00 ^{e,f}	0.33 ± 0.00 ^{f}	12.99 ± 0.58 ^{c,d,e}	0.44 ± 0.01 ^{h}	4.21 ± 0.00 ^{g}
	L3	70.33 ± 0.00 ^{b}	3.70 ± 0.03 ^{d,e}	8.50 ± 0.71 ^{d,e,f}	1.80 ± 0.00 ^{d,e,f}	0.26 ± 0.01 ^{g}	15.67 ± 0.74 ^{c,d,e}	1.80 ± 0.00 ^{a}	5.13 ± 0.00 ^{b}
	L4	65.31 ± 2.07 ^{c}	4.85 ± 0.94 ^{b,c,d}	24.50 ± 0.71 ^{a}	0.35 ± 0.00 ^{f}	0.26 ± 0.01 ^{g}	5.00 ± 3.72 ^{d,e}	0.09 ± 0.00 ^{j}	4.20 ± 0.00 ^{g}
Montería	M1	67.50 ± 1.63 ^{c}	1.81 ± 0.01 ^{f}	5.50 ± 0.71 ^{e,f}	6.77 ± 0.01 ^{a,b}	0.46 ± 0.00 ^{d,e}	18.42 ± 0.95 ^{b,c,d}	0.56 ± 0.02 ^{h}	3.95 ± 0.01 ^{h}
	M2	76.67 ± 0.01 ^{a}	2.05 ± 0.07 ^{e,f}	6.00 ± 0.00 ^{e,f}	0.68 ± 0.01 ^{e,f}	0.40 ± 0.00 ^{e,f}	14.61 ± 0.09 ^{c,d,e}	0.55 ± 0.00 ^{h}	4.27 ± 0.01 ^{f}
Pilot-scale prototype		80.70 ± 0.71	1.30 ± 0.28	6.60 ± 1.13	2.38 ± 0.03	0.05 ± 002	10.25 ± 0.33	2.15 ± 0.05	4.25 ± 0.01

Different superscript lowercase letters in the same column indicate significant differences ($p < 0.05$).

Souzma is a traditional sour strained milk product of Turkophone countries. It is made from a traditional Kyrgyz yogurt, which is salted, then poured into a bag made of cotton, hung to drain, and dried for about a day. It can be diluted and turned into a kind of sour cream or milk. It contains 2.8% protein, 3.2% fat, and 4.2% carbohydrates [33]. *Mabisi* is a fermented milk product widely consumed in Zambia that is produced after the spontaneous fermentation of raw bovine milk. It has lower protein (3–4%), fat (2–4%), and carbohydrate (4–8%) content than most *suero costeño* produced in the department of Córdoba but very similar values in terms of pH (4.1–4.3). It should be noted that, like *masabi*, there are different types of *suero costeño*, which differ in their production methods, region, and producer preferences, giving these products unique physicochemical and sensory properties [3,34]. The pH values of the *suero costeño* were in a range of 3.36 and 5.84; these values are similar to those reported for traditional sour creams such as *amasi* [30], *mabisi* [3], and *nunu* [35]. The lowest pH values (less than 4.0) were those of the serums produced by producers in the municipalities of Sahagún and Chinú (except Ch4), which include the fermentation stage in their processing. The low pH in the fermented milk offers a selective environment for yeast growth but is unfavorable for most bacteria.

The chloride content exhibited a range between 0.09 and 1.8%, which is lower than the values reported for artisanal coastal whey produced in the departments of Córdoba [10] and Bolívar, Colombia [17,36]. The ash content of the *suero costeño* shows high values, especially the samples made in the municipality of Ciénaga de Oro: CO1 (7.66%), CO3 (7.33%), and CO2 (5.37%), Montería: M1 (6.77%), and Cereté: C5 (5.39%). The high values of ash content may be explained by the addition of salt and some additives during the production process and the variability of the raw material used. These values are higher than those found in similar products, such as *staka* (less than 3.42%) [9] and *mabisi* (around 1%) [34].

3.2. Microbiological Quality of Artisanal Suero Costeño

Table 2 shows the aerobic mesophilic counts of the raw milk and some microbiological quality parameters of the artisanal *suero costeño* produced in the department of Córdoba (Colombia). Approximately 75% of the milk used to produce *suero costeño* complies with Colombian regulations, which establish a maximum value of aerobic mesophilic bacteria of 7×10^5 CFU/mL, while only 43.8% complies with the EU regulation (EC853/2004), which establishes a maximum value of aerobic mesophilic bacteria of 1×10^5 CFU/mL. The high mesophilic load found in raw milk in some producers (CO1, CO8, C1, S2, S3, SP1, SP2, and SP3) may result from the lack of good hygiene practices during milking, storage, and transportation, which mostly affects the small producers of artisanal *suero costeño*. To improve the hygienic quality of raw milk, it is necessary to comply with good milking practices [37], maintain the cold chain, and improve the hygiene standards of transport and storage tanks [38].

Table 2. Microbiological parameters of milk and artisanal *suero costeño* (log ufc/g).

Municipality	Artisanal Producer	Milk	*Suero Costeño*			
		Aerobic Mesophilic Bacteria	**Mold and Yeasts**	**Coliforms**	***Escherichia coli***	***Staphylococcus* Coagulase-Positive**
Ciénaga de Oro	CO1	4.92 ± 3.61^{f}	5.03 ± 4.45^{d}	5.18 ± 4.42^{g}	$4.41 \pm 3.56^{e,f}$	0.00 ± 0.00^{e}
	CO2	6.70 ± 5.82^{b}	$6.28 \pm 4.48^{c,d}$	$5.87 \pm 4.72^{f,g}$	$5.76 \pm 5.05^{c,d,e,f}$	$4.87 \pm 4.65^{d,e}$
	CO3	3.65 ± 3.18^{f}	5.66 ± 5.23^{d}	4.76 ± 3.30^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	CO4	$5.80 \pm 5.25^{d,e,f}$	5.38 ± 4.85^{d}	$5.86 \pm 4.60^{f,g}$	$5.7 \pm 5.06^{c,d,e,f}$	4.32 ± 4.05^{e}
	CO5	4.45 ± 3.48^{f}	5.88 ± 5.21^{d}	4.73 ± 3.90^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	CO6	$5.65 \pm 4.75^{d,e,f}$	7.09 ± 5.75^{a}	$5.81 \pm 4.87^{f,g}$	$4.92 \pm 4.26^{d,e,f}$	6.71 ± 5.83^{a}

Table 2. *Cont.*

Municipality	Artisanal Producer	Milk	*Suero Costeño*			
		Aerobic Mesophilic Bacteria	Mold and Yeasts	Coliforms	*Escherichia coli*	*Staphylococcus* Coagulase-Positive
Ciénaga de Oro	CO7	3.81 ± 2.75^{f}	5.56 ± 4.84^{d}	0.00 ± 0.00^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	CO8	$6.18 \pm 5.26^{c,d}$	0.00 ± 0.00^{d}	$5.48 \pm 5.30^{f,g}$	0.00 ± 0.00^{f}	$4.67 \pm 4.37^{d,e}$
	CO9	$4.99 \pm 4.00^{e,f}$	4.75 ± 3.84^{d}	4.51 ± 3.86^{g}	$4.60 \pm 4.00^{e,f}$	3.29 ± 2.06^{e}
Cereté	C1	6.30 ± 4.95^{c}	5.81 ± 5.70^{d}	7.67 ± 6.1^{a}	5.81 ± 4.98^{c}	$4.68 \pm 3.89^{d,e}$
	C2	$5.15 \pm 4.65^{e,f}$	4.90 ± 4.72^{d}	$5.97 \pm 4.30^{e,f,g}$	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	C3	3.88 ± 2.75^{f}	4.38 ± 3.00^{d}	$6.08 \pm 5.38^{e,f}$	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	C4	$5.28 \pm 5.16^{e,f}$	$6.41 \pm 5.96^{c,d}$	$6.26 \pm 5.24^{d,e}$	6.20 ± 5.00^{b}	$6.11 \pm 5.48^{b,c,d}$
	C5	$5.04 \pm 3.00^{e,f}$	5.87 ± 4.90^{d}	4.58 ± 4.55^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
San Pelayo	SP1	$6.00 \pm 4.70^{c,d,e,f}$	5.43 ± 4.86^{d}	$5.28 \pm 4.70^{f,g}$	0.00 ± 0.00^{f}	$6.15 \pm 5.72^{b,c}$
	SP2	6.30 ± 5.21^{c}	$6.43 \pm 5.42^{c,d}$	$5.38 \pm 4.08^{f,g}$	$4.65 \pm 3.78^{e,f}$	0.00 ± 0.00^{e}
	SP3	6.30 ± 5.80^{c}	0.00 ± 0.00^{d}	$6.36 \pm 5.24^{c,d}$	6.36 ± 5.86^{a}	6.61 ± 6.25^{a}
	SP4	4.11 ± 3.91^{f}	$6.23 \pm 4.95^{c,d}$	$6.36 \pm 4.72^{c,d}$	6.36 ± 5.77^{a}	$5.60 \pm 5.02^{c,d,e}$
Chinú	Ch1	4.57 ± 3.54^{f}	$6.38 \pm 5.39^{c,d}$	0.00 ± 0.00^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	Ch2	4.72 ± 3.56^{f}	$6.15 \pm 5.14^{c,d}$	0.00 ± 0.00^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	Ch3	$5.60 \pm 5.71^{d,e,f}$	6.67 ± 4.36^{c}	3.68 ± 2.75^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	Ch4	$5.85 \pm 4.15^{c,d,e,f}$	$6.17 \pm 5.46^{c,d}$	$5.96 \pm 5.24^{e,f,g}$	0.00 ± 0.00^{f}	6.38 ± 5.95^{b}
Sahagún	S1	2.59 ± 1.56^{f}	4.54 ± 3.98^{d}	0.00 ± 0.00^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	S2	7.11 ± 6.30^{a}	5.85 ± 6.02^{d}	0.00 ± 0.00^{g}	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	S3	$6.15 \pm 5.30^{c,d,e}$	5.30 ± 4.64^{d}	0.00 ± 0.00^{g}	3.79 ± 3.56^{f}	0.00 ± 0.00^{e}
	S4	3.79 ± 2.24^{f}	3.61 ± 3.47^{d}	3.57 ± 2.72^{g}	0.00 ± 0.00^{f}	4.20 ± 3.30^{e}
Lorica	L1	$5.60 \pm 4.75^{d,e,f}$	6.92 ± 5.98^{b}	$5.38 \pm 4.75^{f,g}$	0.00 ± 0.00^{f}	0.00 ± 0.00^{e}
	L2	2.99 ± 2.26^{f}	4.96 ± 3.56^{d}	6.49 ± 5.56^{c}	$5.79 \pm 5.20^{c,d}$	0.00 ± 0.00^{e}
	L3	3.18 ± 2.30^{f}	4.96 ± 3.91^{d}	6.49 ± 5.96^{b}	$5.79 \pm 4.70^{c,d,e}$	0.00 ± 0.00^{e}
	L4	3.76 ± 2.98^{f}	5.76 ± 4.98^{d}	3.81 ± 2.90^{g}	0.00 ± 0.00^{f}	$5.04 \pm 4.08^{d,e}$
Montería	M1	$5.77 \pm 4.42^{d,e,f}$	3.23 ± 2.42^{d}	4.28 ± 3.66^{g}	3.76 ± 3.32^{f}	0.00 ± 0.00^{e}
	M2	3.92 ± 2.64^{f}	7.15 ± 6.76^{a}	4.54 ± 3.78^{g}	3.38 ± 2.85^{f}	0.00 ± 0.00^{e}

Different superscript lowercase letters in the same column indicate significant differences ($p < 0.05$).

The samples of artisanal *suero costeño* showed an absence of *Salmonella* spp., consistent with findings reported for *suero costeño* produced in the Bolívar department, Colombia [17], and Bongo, an artisanal fermented product from Uganda [39].

3.2.1. Mold and Yeasts

Regarding the mold and yeast counts, they showed a significant difference ($p < 0.05$) between artisanal producers. Only two (2) producers presented values lower than 5×10^2 CFU/mL (CO8 and SP3), while 94% did not comply with Colombian regulations (2×10^2 and 5×10^2 CFU/mL). This may be due to contamination of the raw material or the production environment during processing [40], which aligns with observations made during visits to the different microenterprises of the producers, many of which process the artisanal *suero costeño* outdoors, under palm roofs, without walls, on porous floors, or in facilities with a deteriorated infrastructure. Specifically, 78.8% of the microenterprises engaged in the production of *suero costeño* are designated as "not acceptable" (compliance < 29.4%), while 21.2% are classified as "acceptable with restrictions" (compliance between 29.5% and 59.9%). These enterprises are predominantly located in the municipalities of Ciénaga de Oro, Chinú, and Montería. It is important to highlight that the presence of molds and yeasts has a significant impact on the shelf life of the product, given that the deterioration caused by these microorganisms constitutes one of the

main challenges for the dairy industry. Additionally, molds can produce mycotoxins that cause health problems for consumers [41]. However, in some traditional fermented dairy products, yeasts are not considered contaminants since they intervene in the fermentation process. In the case of *suero costeño*, yeasts seem to influence fermentation by significantly increasing in abundance during the early stages [33].

3.2.2. Coliforms

The results of the coliform counts are significantly different ($p < 0.05$) between the different artisanal producers (see Table 2). Only 18.75% of the 32 producers of *suero costeño* have coliform values within the permitted range (10–10^2 CFU/mL) according to Colombian regulations (Resolution 1407 of 2022). The high percentage of microenterprises producing whey from the coast that do not comply with the standard is consistent with what has been reported for *suero costeño* produced in the municipality of Montería, Colombia [20] and *amasi*, a Zimbabwean naturally fermented raw milk product [42]. The presence of coliforms in artisanal whey from the coast indicates possible deficiencies in the collection of milk and the infrastructure of microenterprises producing *suero costeño*, as well as a lack of proper hygiene practices during production, storage, and transportation [43].

3.2.3. *Escherichia coli*

Approximately 53% of the *suero costeño* produced by artisanal producers had *E. coli* values within the limits permitted by Colombian regulations, Resolution 1407 (<10 CFU/mL). Samples from microenterprises in the municipalities of Chinú (100%) and Sahagún (75%) showed the best results. The high percentage of *suero costeño* samples (47%) that do not meet the permitted values is consistent with previous reports for *suero costeño* produced in the department of Bolívar [17] and traditional fermented products such as *amasi* [42], and *bogo* [39]. The presence of *E. coli* indicates a deficiency in the cleaning and disinfection processes and conservation methods [44]. This bacterium is responsible for many foodborne diseases [45], and some strains of *E. coli* are indicators of fecal contamination in food and cause intestinal diseases such as enterohemorrhagic colitis [39].

3.2.4. Coagulase-Positive *Staphylococcus*

The results of the coagulase-positive *Staphylococcus* counts are significantly different ($p < 0.05$) among artisanal producers of *suero costeño*. Approximately 59% of artisanal *suero costeño* complies with Colombian regulations (Resolution 1407 of 2022). Producers from the municipalities of Lorica (75%), Montería (100%), Chinú (75%), and Sahagún (75%) were the ones who showed the best results. This is consistent with the low pH values of the *suero costeño* produced in these municipalities, which is an indicator of the quality of the product. The presence of coagulase-positive *Staphylococcus* is an indicator of the lack of hygiene during the production process of artisanal *suero costeño*, poor hygiene practices by handlers, or poor implementation of cleaning and disinfection systems. In dairy products produced in an artisanal way, it may indicate contamination specifically from the normal flora of the skin, mouth, or nasal passages of people who handle the food, which represents a risk due to the capacity of this microorganism to produce enterotoxins that can cause foodborne diseases. In addition, it is important to note that these microorganisms can be widely distributed and can be transmitted directly from milk, either through the external surfaces of the animal or the milking environment [45]. *Staphylococcal* food poisoning results from the ingestion of staphylococcal enterotoxins [38] produced by this microorganism, which can cause mild-to-severe symptoms such as nausea, abdominal pain, vomiting, diarrhea, and weakness [43]. In light of the findings, it is advised that artisanal producers adopt proper hygienic practices during the production process of coastal whey. These practices encompass the utilization of protective equipment, including masks, gloves, hair covers,

and gowns, the implementation of effective manufacturing processes, the execution of thorough cleaning and disinfection procedures, the employment of suitable materials and surfaces, and the use of food-grade packaging materials.

3.3. Rheological Behavior of Suero Costeño

Figure 2 shows the flow curves for *suero costeño* produced in the department of Córdoba, Colombia. Most rheograms (56%) show that the upward and downward curves coincide: there is no hysteresis phenomenon. Thus, this *suero costeño* showed a time-independent behavior. On the other hand, some rheograms (44%) show no correlation between the upward and downward curves; that is, the phenomenon of hysteresis (dependence of behavior with time) is presented. For upward and downward curves, the comparison of independent means showed significant differences between treatments, which corroborates time dependence (thixotropy) in *suero costeño* produced by some producers, mainly from the municipalities of Ciénaga de Oro, Cereté, Chinú, and Monteria, with a thixotropy comprising between 19.5 and 92.8% (Table 3). These high percentages of thixotropy may be due to the addition of some thickeners or stabilizers [46]. This behavior has been reported for dairy cream with some natural stabilizers [14,47], ice cream [48], and yogurt [49]. Furthermore, for the *suero costeño* that shows time dependence, the ascending curve is greater than the descending curve, so they show a positive thixotropy, where the viscosity decreases with time due to a change in the internal structure when a strain is applied.

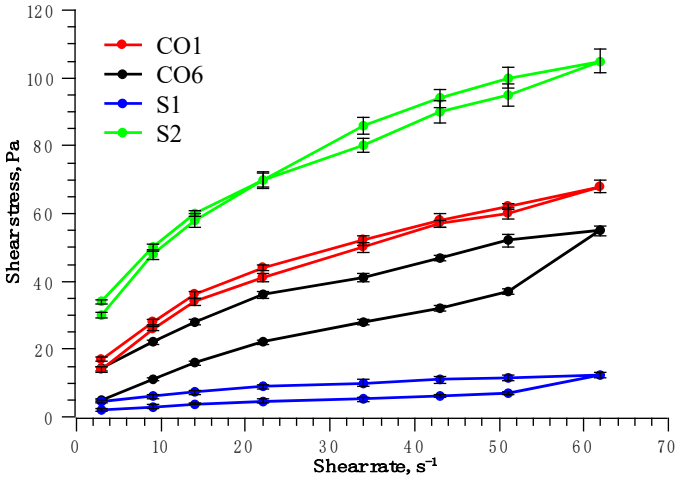

Figure 2. Rheogram of artisanal *suero costeño* produced in the department of Córdoba, Colombia.

Experimental data were adjusted to the Ostwald–de Waele or power law model, which is the most used for dairy products and all adequately represented rheological data (R^2 between 88.4 and 97.9%). The flow behavior index of the rheograms shows values less than one (0.06 to 0.78) (see Table 3), which confirms the pseudoplasticity of *suero costeño*. This behavior is related to changes in the macromolecular organization and can be explained by the structural breakdown of the molecules due to the hydrodynamic forces generated and the increased alignment of the constituent molecules. As the shear rate increases, randomly positioned chains of polymer molecules align in the direction of flow, resulting in less interaction between adjacent polymer chains [50]. Similar results were found in creams with different fermentation levels [4], starch-milk dessert cream [47], low and high fat cream [14], recombined cream [21], sour creams supplemented with milk protein concentrate [6], and whipping cream [14,51]. In general, dairy cream has shear-thinning behavior (pseudoplastic fluid) due to partially aggregated fat globules, which can be broken down at high shear rates [52].

Table 3. Rheological parameters and thixotropy of the power law model in artisanal *suero costeño*.

Municipality	Artisanal Producer	Ascendent		Descendent		Thixotropy, %
		K_{asc}, Pa s^n	n_{asc}	K_{desc}, Pa s^n	n_{desc}	
Ciénaga de Oro	CO1	$10.33 \pm 1.94^{c,d,A}$	$0.46 \pm 0.04^{b,c,A}$	$10.41 \pm 1.31^{d,A}$	$0.46 \pm 0.04^{b,c,A}$	-
	CO2	$7.28 \pm 0.16^{c,d,A}$	$0.57 \pm 0.08^{a,b,A}$	$8.47 \pm 1.67^{d,A}$	$0.54 \pm 0.07^{b,c,A}$	-
	CO3	$6.67 \pm 1.82^{c,d,A}$	$0.54 \pm 0.12^{b,c,A}$	$6.31 \pm 0.84^{d,e\,A}$	$0.53 \pm 0.12^{b,c,A}$	-
	CO4	$6.80 \pm 1.46^{c,d\,A}$	$0.41 \pm 0.09^{c,d,A}$	$6.92 \pm 1.32^{d,e,A}$	$0.42 \pm 0.07^{b,c,A}$	-
	CO5	$5.84 \pm 1.77^{c,d,A}$	$0.49 \pm 0.09^{b,c,B}$	$2.23 \pm 0.44^{e,f,B}$	$0.76 \pm 0.04^{a,A}$	$79.3 \pm 14.8^{a,b}$
	CO6	$8.95 \pm 1.78^{c,d,A}$	$0.44 \pm 0.15^{b,c,B}$	$2.58 \pm 0.28^{e,f,B}$	$0.67 \pm 0.05^{a,b,A}$	81.5 ± 15.8^{a}
	CO7	$13.27 \pm 2.44^{c,d,A}$	$0.18 \pm 0.02^{d,e\,B}$	$1.64 \pm 0.19^{f,B}$	$0.66 \pm 0.03^{a,b,A}$	19.5 ± 3.9^{e}
	CO8	$7.73 \pm 1.71^{c,d,A}$	$0.41 \pm 0.08^{c,d,A}$	$6.90 \pm 1.00^{d,e,A}$	$0.42 \pm 0.07^{b,c,A}$	-
	CO9	$37.11 \pm 4.69^{a,B}$	$0.36 \pm 0.02^{c,d,A}$	$59.9 \pm 5.60^{a,A}$	$0.37 \pm 0.06^{c,d,A}$	54.6 ± 13.5^{d}
Cereté	C1	$27.80 \pm 3.61^{b,c,A}$	$0.09 \pm 0.02^{f,B}$	$26.87 \pm 1.60^{b,c,A}$	$0.34 \pm 0.05^{c,d,A}$	$73.9 \pm 10.6^{b,c}$
	C2	$43.79 \pm 4.43^{a,A}$	$0.09 \pm 0.03^{f,B}$	$30.48 \pm 3.86^{b,c,B}$	$0.38 \pm 0.05^{c,d,A}$	$84.2 \pm 13.2^{a,b}$
	C3	$17.60 \pm 2.05^{c,d,A}$	$0.06 \pm 0.04^{f,A}$	$23.59 \pm 6.41^{b,c,A}$	$0.09 \pm 0.08^{e,A}$	-
	C4	$20.61 \pm 4.33^{b,c,d,A}$	$0.20 \pm 0.12^{d,e,B}$	$5.11 \pm 0.41^{d,e,B}$	$0.58 \pm 0.08^{a,b,A}$	92.8 ± 6.3^{a}
	C5	$11.83 \pm 1.16^{c,d,A}$	$0.23 \pm 0.03^{d,e,B}$	$4.43 \pm 1.01^{e,f,B}$	$0.50 \pm 0.14^{b,c,A}$	$85.3 \pm 7.1^{a,b}$
San Pelayo	SP1	$5.24 \pm 0.86^{c,d,A}$	$0.65 \pm 0.03^{a,A}$	$5.17 \pm 0.41^{d,e\,A}$	$0.68 \pm 0.04^{a,b,A}$	-
	SP2	$13.82 \pm 2.60^{c,d,A}$	$0.50 \pm 0.10^{b,c,A}$	$13.06 \pm 2.12^{d,A}$	$0.50 \pm 0.11^{b,c,A}$	-
	SP3	$6.11 \pm 0.69^{c,d,A}$	$0.62 \pm 0.03^{a,b,A}$	$6.08 \pm 0.50^{d,e\,A}$	$0.62 \pm 0.05^{a,b,A}$	-
	SP4	$2.39 \pm 0.28^{d,A}$	$0.75 \pm 0.08^{a,A}$	$2.17 \pm 0.18^{f,A}$	$0.78 \pm 0.06^{a,A}$	-
Chinú	Ch1	$3.40 \pm 0.14^{d,A}$	$0.32 \pm 0.1^{d,e,A}$	$3.60 \pm 0.63^{e,f,A}$	$0.40 \pm 0.12^{b,c,A}$	-
	Ch2	$9.06 \pm 1.20^{c,d,A}$	$0.23 \pm 0.06^{d,e,B}$	$3.30 \pm 0.26^{e,f,B}$	$0.45 \pm 0.03^{b,c,A}$	$84.6 \pm 7.8^{a,b}$
	Ch3	$10.07 \pm 1.08^{c,d,A}$	$0.25 \pm 0.05^{d,e,B}$	$2.68 \pm 0.20^{e,f,B}$	$0.54 \pm 0.02^{b,c,A}$	89.7 ± 5.1^{a}
	Ch4	$5.24 \pm 0.49^{c,d,A}$	$0.67 \pm 0.04^{a,A}$	$4.43 \pm 0.49^{e,f,B}$	$0.72 \pm 0.05^{a,A}$	23.0 ± 3.6^{e}
Sahagún	S1	$3.19 \pm 0.78^{d,A}$	$0.33 \pm 0.08^{c,d,B}$	$1.71 \pm 0.43^{f,B}$	$0.45 \pm 0.08^{b,c,A}$	$60.3 \pm 9.5^{c,d}$
	S2	$23.15 \pm 3.19^{b,A}$	$0.37 \pm 0.14^{c,d,A}$	$21.68 \pm 2.42^{c,d,A}$	$0.38 \pm 0.14^{c,d,A}$	-
	S3	$11.48 \pm 1.29^{c,d,A}$	$0.52 \pm 0.12^{b,c,A}$	$11.45 \pm 0.89^{d,A}$	$0.44 \pm 0.13^{b,c,A}$	-
	S4	$16.82 \pm 3.77^{c,d,A}$	$0.46 \pm 0.08^{b,c,A}$	$16.30 \pm 3.42^{d,A}$	$0.47 \pm 0.09^{c,d,A}$	-
Lorica	L1	$48.08 \pm 3.32^{a,A}$	$0.17 \pm 0.04^{d,e,A}$	$47.69 \pm 5.19^{a,b,A}$	$0.20 \pm 0.05^{e,A}$	-
	L2	$5.61 \pm 0.51^{c,d,A}$	$0.53 \pm 0.06^{b,c,A}$	$5.37 \pm 0.65^{d,e,A}$	$0.55 \pm 0.04^{b,c,A}$	-
	L3	$3.59 \pm 0.12^{d,A}$	$0.69 \pm 0.01^{a,A}$	$3.73 \pm 0.10^{e,f,A}$	$0.68 \pm 0.01^{a,b,A}$	-
	L4	$5.04 \pm 1.27^{c,d,A}$	$0.57 \pm 0.06^{a,b,A}$	$4.13 \pm 0.88^{e,f,A}$	$0.62 \pm 0.05^{a,b,A}$	-
Montería	M1	$12.06 \pm 2.47^{c,d,A}$	$0.17 \pm 0.04^{d,e,A}$	$7.08 \pm 1.31^{d,e\,B}$	$0.23 \pm 0.06^{d,e,A}$	56.4 ± 14.2^{d}
	M2	$20.65 \pm 3.13^{b,c,A}$	$0.27 \pm 0.03^{d,e,A}$	$14.21 \pm 1.85^{d,B}$	$0.33 \pm 0.03^{c,d,A}$	40.0 ± 14.6^{d}

Different superscript lowercase letters in the same column indicate significant differences ($p < 0.05$). Different superscript capital letters in the same row indicate significant differences ($p < 0.05$) for the ascending and descending rheological parameters (K and n).

ANOVA shows that there are significant differences ($p < 0.05$) between the rheological parameters of the power law (K and n) of the artisanal *suero costeño* produced by the different producers in the municipalities studied. This great variability is due to the raw materials used and the processing method. The flow behavior index (n) showed values between 0.17 and 0.78, except for some *suero costeño* (C1, C2, and C3) produced in the municipality of Cereté (Córdoba, Colombia), which showed a flow behavior index of less than 0.10, so their rheological behavior is very pseudoplastic. The higher shear thinning behavior has the advantage of a decrease in the energy needed during the process conditions of the *suero costeño* (pumping and mixing), and it is also related to a product with better sensory properties (texture).

The consistency coefficient (K) showed values between 1.64 and 48.58 Pa s^n; similar values have been reported for sour creams with different levels of milk protein concentrate (17.6–26.5 Pa s^n) [6] and creams with different fermentation times, 9 h (20.0 Pa s^n) and 12 h (41.96 Pa s^n) [4], but lower than those obtained for creams with the addition of corn starch

(173.64 Pa s^n), potato starch (84.05 Pa s^n), and tapioca starch (161.13 Pa s^n) [47]. *Suero costeño* with a lower viscosity and consistency coefficient will have higher fluidity, which can be associated with better spreadability [53]. In general terms, the *suero costeño* that had the highest consistency coefficient was that made by producers from the municipality of Cereté (Córdoba, Colombia), with average values of 25 and 20 for K_{asc} and K_{des}, respectively. This may be due to the amount of fat (10%) and the milk gel structure induced by lactic acids. A decrease in pH (4.8–5.2) causes the solubilization of colloidal calcium phosphate in casein micelles, which can reduce electrostatic repulsion and promote hydrophobic interactions between the casein micelles, resulting in a three-dimensional gel network [4,6], which presents more resistance to flow.

3.4. Comparison of Artisanal Suero Costeño and That Produced at a Pilot Scale

The suero costeño produced at a pilot scale had the appearance of a soft, homogeneous, viscous, white cream, with the smell and taste characteristics of the handmade product. The Dunnett test showed that the suero costeño produced at the pilot scale was more similar to the products that include the fermentation stage in their elaboration, mainly those from the municipalities of Monteria (M2) and San Pelayo (SP1), with no significant differences in the characteristics of moisture, fat, ash, protein, and pH.

4. Conclusions

Suero costeño is a type of traditional sour cream produced mainly on the Colombian Caribbean coast. The physicochemical characterization of this product shows great variability in terms of moisture, fat, protein, carbohydrate, and ash content due to the raw materials used and processing methods, which vary according to the producer. *Suero costeño* has a fat content that classifies it as a full-fat sour cream (fat $\geq$ 18%) or light sour cream (fat $\leq$ 9%). Its nutritional composition makes it similar to various fermented dairy products traditionally produced in several countries. *Suero costeño* presents high counts of microbial hygiene indicators (molds and yeasts, coliforms, *Escherichia coli,* and coagulase-positive *Staphylococcus aureus*), indicating a low microbiological quality. This can be explained by the poor quality of raw milk, which is not subjected to the pasteurization process during the production of the product. In addition, there is a lack of hygiene in the utensils used for processing, transport, and storage, as well as poor quality during processing and incorrect handling of milk as a raw material. Therefore, it is essential to use milk of high microbiological quality and maintain strict hygienic conditions throughout its production and marketing. *Suero costeño* has a shear-thinning behavior (pseudoplastic fluid) with consistency coefficients ranging from 1.64 to 59.9 Pa.s^n, making it a fairly viscous dairy product. In some cases, it presents thixotropy (19–93%). These parameters must be considered for the design of the different operations (packaging and agitation) and equipment (pumps and pipes) of the *suero costeño* production process and for its scaling up to an industrial level. The *suero costeño* produced at a pilot scale has the appearance of a white cream and is viscous, with the characteristic smell and taste of the artisanal product, and is very similar to the artisanal *suero costeño* that includes the fermentation stage in its production.

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