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Physicochemical 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 and has a variety of uses. The objective was to characterize the physicochemical and rheological properties of "suero costeño" produced in department of Córdoba-Colombia. Samples of " suero costeño " were obtained from local producers, characterized physicochemically (protein, fat, crude fiber, moisture, ash, carbohydrates, chlorides, pH and acidity), and rheologically (stationary tests), adjusting their behavior to the power-law model. The results show great variability in the physicochemical characteristics of the "suero costeño" made by the different artisanal producers, classifying it as a full-fat sour cream or light sour cream, and values of protein, pH and acidity similar to similar traditional dairy products from other countries, such as Reindeer sour cream and Curd or cottage cheese. "Suero costeño" can be classified as a pseudoplastic fluid and depending on the raw materials used and the production process, some present thixotropy, which may be the product of interactions between proteins and fats, which cause changes in the internal structure. Due to this great variability in its physicochemical and rheological characteristics, it is necessary to standardize the process of producing to improve the marketing of this Colombian culinary product.

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

1. Introduction

Fermented cream, also known as sour cream, is a kind of dairy product with a unique acid flavor, which 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, which can extend shelf life and develop the characteristic flavor and texture of dairy products. In addition, lactic acid produced can inhibit the growth of pathogenic and spoilage microorganisms, contributing to the preservation of cultured dairy products [3,4]. Sour creams can be classified into four groups based on their fat content: Full-fat sour cream (fat ≥18%), light sour cream (fat ≤9%), low-fat sour cream (fat ≤6%), and non-fat sour cream (fat ≤1%) [5,6].

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Traditional sour cream is popular in some countries, including Mexico, North America, and Eastern Europe, because of its aromatic taste and creamy texture [6]. Several traditionally fermented cream types are produced worldwide, such as *Créme Fraiche* in France, *Crema Espesa* in Mexico, *Pomazánkové Máslo* in Czech Republic, traditional sour cream in Ukraine, and "Suero Costeño" in Colombia [7]. Suero costeño is an artisanal soured cream produced in 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 [8]. "Suero costeño" can be added to various food items, 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 by 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. The final product is an acidic, soured, and salty fermented milk with a creamy consistency. The time required for obtaining "suero costeño" depends on the desired viscosity [8–10]. 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.

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* [11,12]. Manufacturing standardization, through the utilization of pasteurized milk and commercial dairy cultures, would reduce the sanitary problem but, unfortunately, this will lead to a reduction of the typical sensorial properties of "suero costeño" [9].

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 [13–15]. The objective of this study was to characterize the physicochemical and rheological properties of artisanal "suero costeño" produced in department of Córdoba-Colombia.

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 producer), Cereté (5 artisanal producer), San Pelayo (4 artisanal producer), Chinú (4 artisanal producer), Sahagún (4 artisanal producer), Lorica (4 artisanal producer), and Montería (2 artisanal producer). The samples were transported to the laboratory in ice boxes and stored at 4°C.

2.2. Physicochemical Analyses

The physicochemical analysis of the "suero costeño" was determined according to the Official Methods of Analysis of AOAC International, American Public Health Association (APHA) and International Organization for Standardization (ISO). Samples were analyzed for protein using the Kjeldahl method (AOAC 920.85), fat by the Soxhlet method (AOAC 920.85), crude fiber (AOAC 960.52), moisture content by the loss of mass of samples in an oven heated at 102 ± 2 °C (AOAC 925.10), ash was determined gravimetrically for heated at 550 °C in a muffle furnace (AOAC 925.10), carbohydrates (AOAC 931.02). chlorides (APHA 15.051), pH (AOAC 981.12), and acidity (ISO/TS 22113).

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2.3. Rheological Behavior of "Suero Costeño"

Rheological behavior was measured using the method described by Andrade *et al.* [16] with slight modifications. 100 mL of the "suero costeño" was taken and placed in viscometer VL210003 (FungiLab) with spindle L-4, varying the rotation speed of 1 to 100 rpm in ascending and then in descending form of 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 Ostwald-de-Waele or power-law model (Eq. 1).

$$\boldsymbol{\eta_{app} = K\,\dot{\gamma}^{n-1}} \quad (1)$$

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

The shear rate was obtained by the rotation speed (N, rpm), according to equation 2.

$$\boldsymbol{\dot{\gamma} = 0.263\,n^{-0.771}\,N} \quad (2)$$

Thixotropic properties of "suero costeño" were determined from the area between the upward and downward curves (Eq. 3).

$$\textbf{Thixotropic}, \% = \frac{\int_{\dot{\gamma}_1}^{\dot{\gamma}_2} K_{asc}\,\dot{\gamma}^{nasc} - \int_{\dot{\gamma}_1}^{\dot{\gamma}_2} K_{desc}\,\dot{\gamma}^{ndesc}}{\int_{\dot{\gamma}_1}^{\dot{\gamma}_2} K_{asc}\,\dot{\gamma}^{nasc}}\,\mathbf{100}\% \quad (3)$$

Where K_{asc} and K_{desc} are the consistency coefficient upward and downward, respectively; and n_{asc} and n_{desc} are the flow behavior index upward and downward, respectively.

2.4. Statistical Analysis

One-way analysis of variance (ANOVA) and Tukey's test were performed using JMP Pro 17 software (SAS Institute, NC, USA) to compare significant differences between samples, with a significance level of 5%. All the data were expressed as mean ± standard deviation of triplicate determinations.

3. Results and Discussion

3.1. Physicochemical Analyses

Table 1 shows the values of the physicochemical properties of the "Suero costeño" produced in the department of Córdoba (Colombia). These values are similar to those reported for "suero costeño" produced in Montería [8] and in the department of Bolivar [17], commercial sour creams in the United States [18], Amasi (sour milk from Zulus in South Africa) [19], and Cretan sour cream Staka [7]. 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 Chinú (Ch2), Cereté (C3), and Sahagun (S1) can be considered low-fat sour cream (fat ≤6%). This variability in the 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 the Balkan countries that have fat contents between 30 and 46%, and even *kajmak* contains about 60% of fat, depending on the degree of whey removal [1,7,20].

Table 1. Physicochemical parameters of artisanal "suero costeño".

Municipality	Artisanal producer	Moisture, %	Protein, %	Fat, %	Ash, %	Crude fiber, %	Carbohydrates, %	Chlorides	Acidity, %	pH
Ciénaga de Oro	CO1	60.46±1.92	3.39±0.06	18.00±0.00	11.66±0.66	0.50±0.00	6.50±1.32	0.96±0.01	2.57±0.01	4.86±0.01
	CO2	61.47±1.16	4.94±0.21	12.00±0.00	5.37±1.31	0.21±0.01	16.23±0.06	0.99±0.02	3.49±0.01	4.96±0.00
	CO3	59.93±8.48	7.66±1.00	12.50±0.71	7.33±2.09	0.20±0.01	12.59±10.86	0.15±0.00	2.60±0.01	4.91±0.01
	CO4	76.45±1.08	4.49±0.35	9.00±0.00	2.93±1.97	0.52±0.01	7.15±2.71	0.84±0.00	1.80±0.11	4.34±0.00
	CO5	61.52±0.76	3.76±0.01	8.50±0.71	1.29±0.14	0.26±0.01	24.94±0.19	0.47±0.04	1.46±0.25	4.06±0.01
	CO6	63.03±2.85	3.80±0.04	28.00±1.41	2.25±0.04	0.60±0.00	2.93±1.44	1.09±0.00	2.90±0.04	4.82±0.02
	CO7	44.30±0.18	3.77±0.01	19.00±4.24	4.77±0.00	0.22±0.01	28.17±4.05	0.45±0.00	1.75±0.01	3.36±0.00
	CO8	54.16±4.39	4.97±0.35	8.00±0.00	3.41±0.81	0.74±0.01	29.47±5.55	0.26±0.00	2.56±0.21	5.84±0.01
	CO9	51.35±0.89	2.94±0.25	8.50±0.71	2.41±0.02	0.18±0.00	34.81±0.08	0.19±0.00	3.54±0.00	5.08±0.00
Cereté	C1	63.96±1.22	5.64±0.23	14.50±0.71	3.23±0.01	0.38±0.00	12.68±0.28	1.28±0.00	1.21±0.25	5.04±0.00
	C2	74.67±0.30	4.83±1.11	13.50±0.71	3.36±0.01	0.41±0.00	3.65±0.71	1.25±0.00	1.30±0.07	5.57±0.00
	C3	67.07±0.83	4.25±0.22	5.00±0.00	5.01±0.01	0.48±0.00	18.68±1.06	1.70±0.00	1.47±0.29	3.54±0.00
	C4	56.44±0.78	4.59±0.25	10.00±0.00	4.78±0.01	0.40±0.00	24.20±1.04	1.49±0.00	1.46±0.16	4.63±0.00
	C5	67.70±2.12	7.39±0.01	7.00±1.41	5.39±0.00	0.66±0.00	12.53±3.54	1.65±0.00	1.37±0.17	4.10±0.00
San Pelayo	SP1	74.58±0.98	2.54±0.11	9.50±3.54	2.60±0.00	0.52±0.03	10.79±2.45	1.48±0.00	1.76±0.01	4.78±0.00
	SP2	54.28±1.67	4.63±0.01	25.00±0.00	2.61±0.01	0.22±0.00	13.49±1.68	1.27±0.00	1.65±0.05	3.51±0.00
	SP3	48.85±0.45	4.05±0.99	14.00±2.83	2.66±0.02	0.11±0.00	30.45±3.34	1.44±0.00	2.34±0.06	4.66±0.00
	SP4	47.03±0.72	3.66±0.91	11.00±4.24	3.05±0.00	0.18±0.01	35.27±4.05	1.30±0.00	1.70±0.01	4.45±0.00
Chinú	Ch1	57.59±4.01	8.74±0.04	12.00±1.41	0.05±0.00	0.54±0.00	21.63±5.47	1.72±0.00	2.99±0.04	3.93±0.01
	Ch2	66.03±2.04	6.53±0.36	4.00±0.00	3.25±0.00	0.59±0.01	20.20±1.68	1.34±0.01	3.30±0.06	3.73±0.00
	Ch3	55.27±0.64	7.74±0.02	6.50±0.71	2.39±0.00	0.88±0.00	28.11±1.32	0.22±0.01	3.31±0.08	3.73±0.01
	Ch4	60.34±2.87	4.39±0.52	8.50±0.71	2.80±0.01	0.48±0.00	23.97±2.70	1.45±0.00	2.37±0.13	4.65±0.01
Sahagún	S1	76.04±0.28	6.44±0.02	2.50±0.71	2.52±0.00	0.32±0.01	12.51±0.97	1.23±0.00	2.66±0.03	3.62±0.05
	S2	59.47±0.18	7.73±0.12	15.00±0.01	2.40±0.00	0.89±0.01	15.41±0.30	1.55±0.00	3.17±0.00	3.84±0.00
	S3	66.68±0.23	7.77±0.40	16.50±0.71	1.38±0.01	0.33±0.01	7.68±1.36	1.70±0.00	2.78±0.01	3.69±0.01
	S4	56.19±0.93	8.30±0.11	9.00±0.00	2.73±0.00	0.44±0.00	23.79±0.83	1.43±0.00	1.58±0.42	3.78±0.01
Lorica	L1	76.25±0.06	3.36±0.01	15.00±0.00	2.74±0.00	0.64±0.00	2.66±0.07	0.19±0.00	1.56±0.33	5.60±0.00
	L2	66.42±0.05	5.11±0.63	15.00±0.00	0.49±0.00	0.33±0.00	12.99±0.58	0.44±0.01	2.83±1.35	4.21±0.00
	L3	70.33±0.00	3.70±0.03	8.50±0.71	1.80±0.00	0.26±0.01	15.67±0.74	1.80±0.00	2.43±1.63	5.13±0.00
	L4	65.31±2.07	4.85±0.94	24.50±0.71	0.35±0.00	0.26±0.01	5.00±3.72	0.09±0.00	1.92±0.92	4.20±0.00
Montería	M1	67.50±1.63	1.81±0.01	5.50±0.71	6.77±0.01	0.46±0.00	18.42±0.95	0.56±0.02	3.00±0.62	3.95±0.01
	M2	76.67±0.01	2.05±0.07	6.00±0.00	0.68±0.01	0.40±0.00	14.61±0.09	0.55±0.00	2.80±0.00	4.27±0.01

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ANOVA shows 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 is 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 nonliquid 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 the "suero costeño" is not carried out. Curd contains 8.9% fat, and 6.5% protein [21]. These products have similar physicochemical properties (fat, protein) to the "suero costeño" produced in the municipalities of Cereté (C3, C4 and C5) and Chinú (Ch1 and Ch2). The high protein content presented in the "suero costeño" from theses municipalities may be due to the addition of whey protein during its production.

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 dry 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 [22]. 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%) contents than most "suero costeño" produced in the department of Córdoba, but very similar values in terms of acidity (1-2% lactic acid) and pH (4.1 – 4.3). It should be noted that, like coastal whey, there are different types of mabisi, which differ in the production methods, region, and producer preferences, giving these products unique physicochemical and sensory properties [23,24]

The ash content of the "suero costeño" presents high values, especially the samples made in the municipality of Cienaga de oro (CO1, CO2, CO3 and CO7), Montería (M1), and Cereté (C3, C4, and C5). The high values of ash content may be due to the fact that some producers add salt and some preservatives. These values are higher than those found in similar products, such as staka (less than 3.42%) [7], and mabisi (around 1%) [23].

3.2. Rheological Behavior of "Suero Costeño"

Figure 1 shows the flow curves for "suero costeño" produced in department of Córdoba-Colombia. Most rheograms (56%) show that upward and downward curves coincide: there is no hysteresis phenomenon. Thus, these "sueros costeños" showed a time-independent behavior. On the other hand, some rheograms (44%) show no coincidence 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 difference between treatments, which corroborates time dependence (thixotropy) in "suero costeño" produced by some productors, mainly from the municipalities of Cienaga de Oro, Cereté, Chinú y Monteria, with a thixotropy comprised between 19.5 and 92.8% (Table 2). These high percentages of thixotropy may be due to the addition of some thickeners or stabilizers [25]. This behavior has been reported for dairy cream with some natural stabilizers [26,27], ice cream [28], and yogurt [29]. Furthermore, for the "sueros costeños" that present 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 of the internal structure when a strain is applied.

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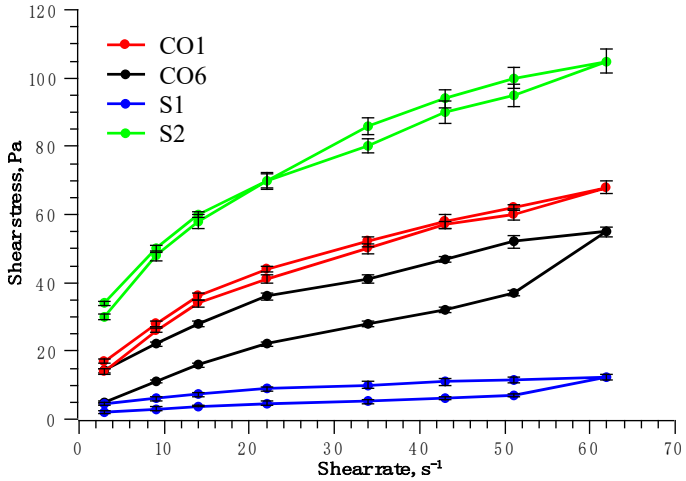

Figure 1. Rheogram of artisanal "suero costeño" produced in the department of Cordoba-Colombia.

Table 2. Rheological parameters and thixotropy of 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±1.94	0.46±0.04	10.41±1.31	0.46±0.04	-
	CO2	7.28±0.16	0.57±0.08	8.47±1.67	0.54±0.07	-
	CO3	6.67±1.82	0.54±0.12	6.31±0.84	0.53±0.12	-
	CO4	6.80±1.46	0.41±0.09	6.92±1.32	0.42±0.07	-
	CO5	5.84±1.77	0.49±0.09	2.23±0.44	0.76±0.04	79.3±14.8
	CO6	8.95±1.78	0.44±0.15	2.58±0.28	0.67±0.05	81.5±15.8
	CO7	13.27±2.44	0.18±0.02	1.64±0.19	0.66±0.03	19.5±3.9
	CO8	7.73±1.71	0.41±0.08	6.90±1.00	0.42±0.07	-
	CO9	37.11±4.69	0.36±0.02	59.9±5.60	0.37±0.06	54.6±13.5
Cereté	C1	27.80±3.61	0.09±0.02	26.87±1.60	0.34±0.05	73.9±10.6
	C2	43.79±4.43	0.09±0.03	30.48±3.86	0.38±0.05	84.2±13.2
	C3	17.60±2.05	0.06±0.04	23.59±6.41	0.09±0.08	-
	C4	20.61±4.33	0.20±0.12	5.11±0.41	0.58±0.08	92.8±6.3
	C5	11.83±1.16	0.23±0.03	4.43±1.01	0.50±0.14	85.3±7.1
San Pelayo	SP1	5.24±0.86	0.65±0.03	5.17±0.41	0.68±0.04	-
	SP2	13.82±2.60	0.50±0.10	13.06±2.12	0.50±0.11	-
	SP3	6.11±0.69	0.62±0.03	6.08±0.50	0.62±0.05	-
	SP4	2.39±0.28	0.75±0.08	2.17±0.18	0.78±0.06	-
Chinú	Ch1	3.40±0.14	0.32±0.1	3.60±0.63	0.40±0.12	-
	Ch2	9.06±1.20	0.23±0.06	3.30±0.26	0.45±0.03	84.6±7.8
	Ch3	10.07±1.08	0.25±0.05	2.68±0.20	0.54±0.02	89.7±5.1
	Ch4	5.24±0.49	0.67±0.04	4.43±0.49	0.72±0.05	23.0±3.6
Sahagún	S1	3.19±0.78	0.33±0.08	1.71±0.43	0.45±0.08	60.3±9.5
	S2	23.15±3.19	0.37±0.14	21.68±2.42	0.38±0.14	-
	S3	11.48±1.29	0.52±0.12	11.45±0.89	0.44±0.13	-
	S4	16.82±3.77	0.46±0.08	16.30±3.42	0.47±0.09	-
Lorica	L1	48.08±3.32	0.17±0.04	47.69±5.19	0.20±0.05	-
	L2	5.61±0.51	0.53±0.06	5.37±0.65	0.55±0.04	-
	L3	3.59±0.12	0.69±0.01	3.73±0.10	0.68±0.01	-
	L4	5.04±1.27	0.57±0.06	4.13±0.88	0.62±0.05	-
Montería	M1	12.06±2.47	0.17±0.04	7.08±1.31	0.23±0.06	56.4±14.2
	M2	20.65±3.13	0.27±0.03	14.21±1.85	0.33±0.03	40.0±14.6

Experimental data were adjusted to 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%).

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Flow behavior index of the rheograms presents values less than one (0.06 to 0.78) (see Table 2), which confirm the pseudoplasticity of "suero costeño". This is related to changes in the macromolecular organization. As the shear rate increases, randomly positioned chains of polymer molecules align in the direction of the flow, resulting in less interaction between adjacent polymer chains [30]. Similar results were found in creams with different fermentation levels [3], starch-milk dessert cream [27], low and high fat cream [26], recombined cream [13], sour creams supplemented with milk protein concentrate [5], and whipping cream [31]. 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 [32].

ANOVA shows that there are significant differences between the rheological parameters of the power law (K and n) of the artisanal "suero costeño" produced by the different producers of the municipalities studied, this is due to the raw materials used and the processing method, which makes this product to have a great variability. Flow behavior index (n) presented values between 0.17 and 0.78, with the exception of some "sueros costeños" (C1, C2, C3) produced in the municipality of Cereté (Córdoba-Colombia), which showed flow behavior index less than 0.10, so their rheological behavior is very pseudoplastic.

The consistency coefficient (K) presented 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) [5], creams with different fermentation times: 9 h (20.0 Pa s^n) and 12 h (41.96 Pa s^n) [3], 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) [27]. In general terms, the "suero costeño" that presented the highest consistency coefficient were those 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 and the low percentage of acidity, which can affect the electrostatic repulsion and hydrophobic interactions between the casein micelles, and therefore the three-dimensional gel network [3]

4. Conclusions

"Suero costeño" is a type of traditional sour cream produced mainly on the Colombian Caribbean coast. The physicochemical characterization of this product showed 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 ≥18%) or light sour cream (fat ≤9%); and presents a nutritional composition that makes it similar to various fermented dairy products traditionally produced in several countries. "Suero costeño" has a shear-thinning behavior (pseudoplastic fluid) and in some cases it presents thixotropy.

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