Cupuassu (*Theobroma grandiflorum*) pulp, probiotic, and prebiotic: Influence on color, apparent viscosity, and texture of goat milk yogurts

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ABSTRACT

Cupuassu is an acidic fruit that has a characteristic aroma, flavor, and texture; its fiber-rich pulp can provide a different consistency than other fruit pulps. Goat milk is an excellent source of amino acids, fatty acids, and minerals, and is widely used for processing fermented milks, such as yogurt. However, compared with cow milk yogurts, it is difficult to make goat milk yogurts with a good consistency. Therefore, it is necessary to use certain technological strategies. This study was carried out to investigate the possibility of adding cupuassu pulp, probiotic (*Lactobacillus acidophilus* LA-5), and prebiotic (inulin) to improve the texture of goat milk yogurt. A total of 6 treatments were performed: natural (N), probiotic (Pro), prebiotic (Pre), synbiotic (S), cupuassu (C), and probiotic with cupuassu (PC). The viability of probiotic in yogurts (Pro, S, and PC) was evaluated. In addition, instrumental analyses (pH, color, apparent viscosity, and texture) were performed to evaluate the influence of these different ingredients on goat milk yogurts. The probiotic bacteria remained viable ($\geq 7 \log \text{cfu} \cdot \text{mL}^{-1}$) throughout the 28 d of refrigerated storage, which exceeded the minimum count required to confer probiotic physiological benefits. The pH levels of the yogurts inoculated with *L. acidophilus* (Pro, S, and PC) were lower than others yogurts (N, Pre, and C). However, all yogurt samples underwent gradual decreases in pH until 7 to 14 d of storage. The lightness (L^*) was affected initially by addition of all ingredients (cupuassu pulp, probiotic, and prebiotic). The addition of cupuassu pulp (C and PC) increased the L^* during the period of storage. Apparent viscosity and firmness decreased in the PC yogurt. The consistency was highest in the yogurts with added prebiotic (Pre and S) than the other yogurts (N, Pro, C, and PC) at the end of the storage period (d 28). The cohesiveness remained constant in all yogurts (N, Pro, Pre, S, C, and PC). Based on the results obtained from the current

study, it was concluded that cupuassu pulp addition improves the texture of goat milk yogurts. Therefore, this pulp could be an important technological strategy for the dairy goat industry.

Key words: instrumental analysis, *Lactobacillus acidophilus* LA5, consistency, caprine milk

INTRODUCTION

Cupuassu (*Theobroma grandiflorum*) is a tropical fruit native to the Brazilian Amazon. Cupuassu has a high economic potential because of its excellent characteristics such as aroma, flavor, and texture (Faber and Yuyama, 2015). However, because of its distinctive flavor, cupuassu pulp is used as an ingredient in the manufacture of ice cream, juice, liquors, wines, jellies, and other products, such as yogurts, rather than being consumed *in natura* (Vriesmann and Petkowicz, 2009; Salgado et al., 2013). Cupuassu is a potential source of dietary fiber, mainly soluble fiber (Salgado et al., 2011). The cupuassu pulp has a particular chemical composition, rich in fibers, and contains a considerable amount of starch as well as pectin polysaccharides (Vriesmann et al., 2009), which can provide a different texture than other fruit pulps.

Goat milk is an excellent source of FA, protein, and minerals. When compared with cow milk, goat milk has the following characteristics: (1) less soluble and more insoluble contents of volatile FA, (2) a higher percentage of medium- and short-chain FA, (3) casein micelle with a lower percentage of α_{S1} -casein fraction, (4) smaller size of casein micelle, and (5) more calcium and inorganic phosphorus (Park et al., 2007). Furthermore, the importance of goat milk as a functional food is due to its high digestibility and nutritional value, as well as its therapeutic and dietary characteristics (Park et al., 2007; Fonseca et al., 2013). For these reasons, it is an excellent substitute for cow milk in the nutrition of children and elderly persons (Park et al., 2007; Kapila et al., 2013). Goat milk is widely used for processing fermented milks and other dairy products. Yogurt is the most widely produced and consumed fermented milk and is used as a vehicle for probiotic cultures and

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prebiotics (Costa et al., 2013; Costa and Conte-Junior, 2013). However, compared with cow milk yogurt, it is difficult to make goat milk yogurt with an appropriate flavor (Costa et al., 2014) and consistency, which is mainly due to the difference in casein composition and content (Li and Guo, 2006). Micelle structures of goat milk differ from cow milk in average diameter, hydration, and mineralization (Park et al., 2007). Therefore, it is necessary to use certain technological strategies. One alternative is the addition of inulin or another type of fiber, such as that present in fruit pulp (Buriti et al., 2014).

Inulin is one of the most studied and widely used prebiotics, with advantageous technological and nutritional properties (Paseephol et al., 2008). Prebiotics are selectively fermented ingredients that allow specific changes in the composition, activity, or both, of gastrointestinal microbiota, which confers a health benefit on the host (Gibson, 2007). Depending on the concentration, inulin may increase its effect on the structure and texture of dairy products, such as yogurt. Addition of inulin can change the texture and rheological properties of dairy foods (Paseephol et al., 2008).

Probiotics are live microorganisms, which when administered in adequate amounts, may benefit the health of the host (Sanders, 2009). *Lactobacillus acidophilus* LA-5 strain exhibits viability in milk matrix, such as fermented milks (Costa et al., 2015). However, no reports are present in the literature that this probiotic can improve the texture of goat milk yogurt. Certain strains of *Lactobacillus*, such as *Lactobacillus delbrueckii* ssp. *bulgaricus*, have this ability (Shihata and Shah, 2002).

In this context, the aim of the present study was to improve the texture of goat milk yogurt by adding cupuassu pulp, probiotic, prebiotic, or a combination of these.

MATERIALS AND METHODS

Goat Milk Yogurts

Ten liters of goat milk yogurts were produced as described by Costa et al. (2014) with modifications. In all treatments, thermophilic yogurt cultures (1% vol/vol; YF-L903, Chr. Hansen, Valinhos, Brazil) were added in UHT goat whole milk (Cappry's, Rio Grande do Sul, Brazil). A total of 6 treatments were performed: natural (**N**) containing milk and yogurt cultures; probiotic (**Pro**) containing milk, yogurt cultures, and probiotic; prebiotic (**Pre**) containing milk, yogurt cultures, and inulin; synbiotic (**S**) containing milk, yogurt cultures, probiotic, and inulin; cupuassu (**C**) containing milk, yogurt cultures, and cupuassu pulp; and probiotic with

cupuassu (**PC**) containing milk, yogurt cultures, probiotic, and cupuassu pulp. For treatments with a probiotic (Pro, S, and PC), *L. acidophilus* culture (LA-5; Chr. Hansen) was inoculated at a concentration of 5% (vol/vol) in relation to the total milk volume used to produce the probiotic. For treatments with a prebiotic (Pre and S), 5% (wt/vol) of inulin (Ingredients & Systems Biotechnology, São Paulo, SP, Brazil) was added. The inulin polymer has a degree of polymerization from 2 to 50 with an average degree of polymerization of 9. For the treatments with cupuassu (C and PC), 10% (wt/vol) pasteurized cupuassu pulp (Polpa de Fruta, Macapá, AP, Brazil) was added.

The yogurt mixtures were fermented in an oven at $43 \pm 2^\circ\text{C}$. The fermentation was interrupted when the pH (AOAC International, 2012) reached 4.5. Finally, the product was packaged in 500-mL plastic pots and stored at $4 \pm 2^\circ\text{C}$ for 28 d. The physicochemical analysis and probiotic viability assay were performed during the storage period (0, 7, 14, 21, and 28 d). This experiment was repeated 3 times ($n = 3$), and all analyses were performed in triplicate.

Bacteriological Analysis and Survivability of Probiotic

Streptococcus thermophilus and *Lactobacillus delbrueckii* ssp. *bulgaricus* were analyzed after the yogurt was prepared (d 1) to characterize the fermented product as yogurt. Enumeration of *S. thermophilus* was performed on M17 agar with lactose, which was incubated under aerobiosis at 37°C for 2 d. The count of *L. delbrueckii* ssp. *bulgaricus* on de Man, Rogosa and Sharpe (MRS) agar with pH 5.4 was performed after incubation under anaerobiosis at 37°C for 3 d (Codex Alimentarius, 2010). The probiotic (*L. acidophilus* LA-5) was counted according to the procedures of Costa et al. (2014), during the storage period (0, 7, 14, 21, and 28 d). *Lactobacillus acidophilus* was grown on MRS agar supplemented with 0.15% (wt/vol) bile salts, and aerobically incubated at 37°C for 2 d.

Physicochemical Analysis

pH Determination. Samples of goat milk yogurts were also analyzed for pH, using a digital pH meter (model PG1800, Cap Lab, SP, Brazil; AOAC International, 2012).

Instrumental Color. Color determinations were made at 5°C by means of a Minolta CM-600D spectrophotometer (Minolta Camera Co., Osaka, Japan). The colorimeter was previously calibrated with illuminant D65 and a 2° standard observer. Yogurt samples (50 mL) at 5°C were stirred and placed in an aluminum cyl-

inder (outside diameter 55 mm), with the surface optically flat before measuring, and the sensor was mounted directly on top of the cylinder to prevent ambient light noise. The color space of the yogurts was studied, and the following color coordinates were determined: lightness (L^* , 100 = white, 0 = black), redness (a^* , +red, -green), and yellowness (b^* , +yellow, -blue). These analyses were performed in triplicate.

Apparent Viscosity and Instrumental Texture Analysis

The apparent viscosities of the yogurts samples (100 mL) were measured at 5°C using a Quimis viscometer (Viscosímetro Rotativo Microprocessado, Q860M21, SP, Brazil) equipped with rotor no. 3, mixing at 60 rpm. The apparent viscosity was measured in triplicate.

Texture was assessed using a texture analyzer (TA-XT.Plus, Stable Micro Systems Ltd., Surrey, UK) equipped with a 50-kgf load cell, according to Ilić et al. (2014). Texture profile analysis (TPA) was used, analyzing firmness, consistency, and cohesiveness. The samples (100 mL) were compressed at 10% of original height with a back extrusion cell (A/BE) disc (diameter 36 mm; distance 30 mm; speed 0.001/ms), at a temperature of 4°C, with 3 measurements per sample averaged for data analysis. The tests were carried out in a standard size back extrusion container (50 mm in diameter). The extrusion disc was positioned centrally over the sample container.

Statistical Analysis

The results for color, pH, apparent viscosity, texture, and *L. acidophilus* LA-5 were subjected to one-way ANOVA, considering treatments and days as sources of variation. All ANOVA were subjected to Tukey's test at $P < 0.05$ using XLSTAT version 2013.2.03 (Addinsoft, Paris, France). The mean bacteria counts were calculated and expressed as $\log_{10}$ cfu·g⁻¹.

RESULTS AND DISCUSSION

Bacteriological Analysis

The counts of *S. thermophilus* and *Lactobacillus delbrueckii* ssp. *bulgaricus* were evaluated to characterize the products made with yogurts, which was analyzed only on d 1. The yogurts contained, respectively, for *S. thermophilus* and *L. delbrueckii* ssp. *bulgaricus*: 11.37 and 7.30 (N), 11.34 and 7.62 (Pro), 11.44 and 10.73 (Pre), 9.10 and 7.97 (S), 9.02 and 7.9 (C), and 11.16 and 11.13 (PC) $\log$ cfu·g⁻¹. Thus, the fermented milks produced in all treatments (N, Pro, Pre, S, C, and PC)

were considered to be yogurt, the starter cultures in all the products were higher than 7 $\log$ cfu·g⁻¹ (Codex Alimentarius, 2010).

For the probiotic yogurts, *L. acidophilus* LA-5 initial values were 11.01, 9.11, and 11.29 $\log$ cfu·g⁻¹ for Pro, S, and PC yogurts, respectively. In general, the addition of inulin did not influence the probiotic viability (Bedani et al., 2013). However, in our study the treatment with inulin (S) had the lowest initial value of probiotic, which suggests an interference of this ingredient in the development of this microorganism. Figure 1 demonstrates the behavior of the probiotic in all probiotic goat milk treatments. The viability of the probiotic bacteria decreased ($P < 0.05$) in all treatments (Pro, S, and PC) during the first week of storage. The decrease of *L. acidophilus* LA-5 can be explained by 3 mechanisms: the depletion of some nutrients needed by probiotic bacteria; probiotic may have upset the desirable relationship between the yogurt starter culture; and probiotic in the yogurt may have initially produced higher concentrations of antimicrobials such as bacteriocins, H₂O₂, or organic acids that may have eventually inhibited more *L. acidophilus* (Olson and Aryana, 2008).

Thereafter, they were stable, and all probiotic yogurts maintained counts $\geq 7 \log$ cfu·g⁻¹ during 4 wk (28 d) of storage. *Lactobacillus acidophilus* LA-5 demonstrated variable viability in the yogurts, with final counts of 9.40, 8.02, and 8.43 $\log$ cfu·g⁻¹ for Pro, S, and PC yogurts, respectively. These counts exceeded the minimum count required to confer probiotic physiological benefits (Bedani et al., 2013; Costa et al., 2013). Regarding the lower viability of the PC yogurts than Pro and S, Kailasapathy et al. (2008) suggested that probiotic strains can be influenced by the pH of the fruit preparation.

pH Analysis

The pH of the goat milk used to produce the yogurts was 6.62 ± 0.03 . The pH values of the N, Pro, Pre, S, C, and PC yogurts are presented in Table 1. The reduction ($P < 0.05$) of milk pH after yogurt production (d 0), in all treatments, was in line with the growth of the starter culture and the probiotic bacteria. The pH of all yogurt samples decreased ($P < 0.05$) gradually until 7 to 14 d of storage, and then increased ($P < 0.05$) in Pre and C treatments. The high bacterial metabolic activity ferments lactose and produces lactic acid, which decreases the pH of yogurts (Gaspar et al., 2013). However, when the sugar sources are exhausted, microorganisms begin to consume proteins and start to produce other metabolites, such as biogenic amines (Costa et al., 2015), which increase the pH (Vahedi et al., 2008). This explains the pH increase of Pre and C

Figure 1. Counts of *Lactobacillus acidophilus* LA-5 (log cfu·g⁻¹) in goat milk yogurts with added probiotic (Pro), synbiotic (S) and probiotic with cupuassu (PC) goat milk yogurts during 28 d of storage. Different uppercase letters (A–C) indicate significant differences among goat milk yogurts, $P < 0.05$; different lowercase letters (a–d) indicate significant differences among storage times, $P < 0.05$.

yogurts ($P < 0.05$) at the end of the storage period (21 and 28 d).

Although all yogurts were cooled at pH 4.5, the pH levels of the yogurts inoculated with *L. acidophilus* (Pro, S, and PC) were lower ($P < 0.05$) than the pH levels of the remaining yogurts (N, Pre, and C) at the end of storage. Espírito Santo et al. (2011) observed similar behavior, and suggested that the occurrence of fatty acid consumption as a carbon source after sugar depletion and fiber pectin degradation to uronic acids could explain the pH reduction. Moreover, the probiotic bacteria may have produced organic acids (Olson and Aryana, 2008), which contributes to decreasing pH.

Instrumental Color Analysis

The color parameters L^* , a^* , and b^* exhibited some differences ($P < 0.05$), and these changes in color in the 6 goat milk yogurts (N, Pro, Pre, S, C, and PC) stored at 4°C for 28 d are presented in Table 2.

The L^* is lightness, in which 100 represents white, whereas zero represents the black. The L^* values were significantly affected by the addition of the cupuassu pulp, probiotic, and prebiotic (Pro, Pre, S, C and PC) on the initial day ($P < 0.05$); however, at the end of the storage period no difference were found between treatments. The L^* values in all yogurt (N, Pro, Pre, S, C, and PC) samples increased ($P < 0.05$) during the 28 d of storage. The white color of milk results

from the presence of colloidal particles, such as milk fat globules and casein micelles, capable of scattering light in the visible spectrum (García-Pérez et al., 2005). In addition, the goat milk has the absence of β -carotene because of a physiological process of the goats. This substance is converted into vitamin A (Park et al., 2007), which explains the high L^* values, mainly in N yogurt. The goat milk yogurt sample containing cupuassu pulp (C and PC) had a lower L^* value than others (N, Pro, Pre, and S). These results suggest that the cupuassu pulp decreased the lightness values of the yogurts, which can be related to this fruit pulp color. Silva and Silva (1999) observed that cupuassu pulp exhibits a light yellow color (L^* 70.04, a^* 26.36, and b^* 19.73), which consequently can change the yogurt color (C and PC). This difference probably could be well accepted by consumers, as it would reflect the presence of cupuassu. Changes in yogurt color are in agreement with milk substitution, which may be attributed to the different opacity level of gels. This fact increases with the casein proportion and their aggregation level (González-Martínez et al., 2002).

As for the storage period, the L^* value increased ($P < 0.05$) in all treatments (N, Pro, Pre, S, C, PC). Although, the greatest change occurred in Pro, where the L^* value increased from 89.24 to 92.39. As the result of Pre and S, some studies achieved the same effect, which demonstrated that inulin increase L^* value (Nozière et al., 2006; Villegas et al., 2010). However, this result dif-

Table 1. pH values (means $\pm$ standard deviation) of goat milk yogurts measured during the storage period at 4°C

Treatment ¹	Storage period (d)				
	0	7	14	21	28
N	4.57 ^{a,A} $\pm$ 0.04	4.42 ^{c,A} $\pm$ 0.01	4.48 ^{bc,B} $\pm$ 0.01	4.51 ^{b,A} $\pm$ 0.03	4.57 ^{a,A} $\pm$ 0.01
Pro	4.45 ^{ab,B} $\pm$ 0.08	4.38 ^{bc,B} $\pm$ 0.05	4.47 ^{a,B} $\pm$ 0.02	4.38 ^{c,B} $\pm$ 0.01	4.37 ^{c,C} $\pm$ 0.03
Pre	4.55 ^{a,A} $\pm$ 0.01	4.41 ^{b,AB} $\pm$ 0.05	4.54 ^{b,A} $\pm$ 0.08	4.51 ^{a,A} $\pm$ 0.06	4.47 ^{ab,B} $\pm$ 0.01
S	4.42 ^{a,B} $\pm$ 0.04	4.27 ^{c,D} $\pm$ 0.05	4.35 ^{ab,C} $\pm$ 0.05	4.26 ^{c,C} $\pm$ 0.01	4.34 ^{b,C} $\pm$ 0.01
C	4.43 ^{c,B} $\pm$ 0.02	4.35 ^{d,C} $\pm$ 0.05	4.60 ^{a,A} $\pm$ 0.08	4.51 ^{b,A} $\pm$ 0.02	4.53 ^{b,AB} $\pm$ 0.03
PC	4.50 ^{a,AB} $\pm$ 0.01	4.28 ^{bc,D} $\pm$ 0.01	4.24 ^{c,D} $\pm$ 0.01	4.28 ^{bc,C} $\pm$ 0.02	4.30 ^{b,C} $\pm$ 0.01

^{a-d}Different lowercase superscripts indicate significant differences among storage times, $P < 0.05$.

^{A-D}Different uppercase superscripts indicate significant differences among goat milk yogurts, $P < 0.05$.

¹N = natural; Pro = probiotic; Pre = prebiotic; S = synbiotic; C = cupuassu; PC = probiotic with cupuassu.

fers from those found by Mani-López et al. (2014), who observed no changes in color parameters during storage. This difference may related to distinct factors such as the probiotic strain (*L. acidophilus*, *Lactobacillus casei*, and *Lactobacillus reuteri*), the absence of inulin, and the type of milk (cow milk), which depending on combination of the ingredients could generate a unique color profile (Mani-López et al., 2014).

Regarding a^* (greenness-redness) initial values, treatments added with prebiotic (Pre and S) and cupuassu pulp (C and PC) differed from control ($P < 0.05$). However, Pre and S had lower values, whereas C and PC had higher values. Kim et al. (2011) reported the same behavior of Pre and S treatments, which can be explained by the addition of inulin that increases the water-holding capacity. In all treatments (N, Pro, Pre, S, C, and PC), during storage, an increase of a^* values

was observed ($P < 0.05$), indicating an increase in the redness of the yogurts. Estrada et al. (2011) explained this increase through the gel stirring and acidity changes in yogurt during refrigerated storage, because they may cause changes in tissue structure that result in leakage of natural pigments, such as carotenoids, to the yogurt matrix.

The b^* (blueness-yellowness) values was different between all treatments, and the N treatment was less yellow than the other treatments (Pro, Pre, S, C, and PC). The greater yellowness ($P < 0.05$) of Pro, Pre, S, C, and PC can be attributed to the addition of cupuassu pulp, and probiotic and prebiotic ingredients, which all differed from N. Yellowness of the yogurt depends on the type and level of fruit or fiber. Similar results were described for yogurts fortified with commercial apple fiber (Staffolo et al., 2004), orange fiber (García-Pérez

Table 2. The color values (means $\pm$ standard deviation) of goat milk yogurt measured at 4°C during the storage period

Property ¹	Treatment ²	Storage period (d)				
		0	7	14	21	28
L^*	N	90.05 ^{e,A} $\pm$ 0.01	90.22 ^{d,A} $\pm$ 0.05	90.40 ^{c,A} $\pm$ 0.02	90.71 ^{b,A} $\pm$ 0.02	92.78 ^{a,A} $\pm$ 0.02
	Pro	89.24 ^{d,C} $\pm$ 0.01	89.90 ^{c,B} $\pm$ 0.04	90.06 ^{c,B} $\pm$ 0.02	90.88 ^{b,A} $\pm$ 0.08	92.39 ^{a,A} $\pm$ 0.10
	Pre	89.41 ^{e,B} $\pm$ 0.02	89.83 ^{d,B} $\pm$ 0.01	90.13 ^{c,B} $\pm$ 0.03	90.89 ^{b,A} $\pm$ 0.18	92.43 ^{a,A} $\pm$ 0.03
	S	89.06 ^{d,D} $\pm$ 0.01	89.45 ^{c,C} $\pm$ 0.00	89.68 ^{c,C} $\pm$ 0.01	90.58 ^{b,A} $\pm$ 0.17	92.05 ^{a,A} $\pm$ 0.02
	C	87.76 ^{c,F} $\pm$ 0.01	88.44 ^{b,D} $\pm$ 0.01	87.90 ^{c,E} $\pm$ 0.04	88.33 ^{b,B} $\pm$ 0.08	90.17 ^{a,B} $\pm$ 0.13
	PC	88.09 ^{c,E} $\pm$ 0.01	88.33 ^{c,E} $\pm$ 0.01	88.07 ^{c,D} $\pm$ 0.02	88.78 ^{b,B} $\pm$ 0.23	89.70 ^{a,B} $\pm$ 0.01
	N	-1.74 ^{d,B} $\pm$ 0.02	-1.69 ^{d,A} $\pm$ 0.03	1.99 ^{c,A} $\pm$ 0.01	2.09 ^{b,C} $\pm$ 0.02	2.37 ^{a,B} $\pm$ 0.01
a^*	Pro	-1.74 ^{d,B} $\pm$ 0.01	-1.86 ^{e,B} $\pm$ 0.04	1.85 ^{c,A} $\pm$ 0.01	2.32 ^{a,A} $\pm$ 0.03	2.20 ^{b,D} $\pm$ 0.02
	Pre	-1.78 ^{d,C} $\pm$ 0.01	-2.01 ^{e,C} $\pm$ 0.02	1.62 ^{c,A} $\pm$ 0.02	2.19 ^{b,BC} $\pm$ 0.05	2.21 ^{a,DC} $\pm$ 0.01
	S	-1.78 ^{de,C} $\pm$ 0.01	-2.04 ^{e,C} $\pm$ 0.02	1.81 ^{c,A} $\pm$ 0.04	2.35 ^{a,A} $\pm$ 0.01	2.24 ^{b,DC} $\pm$ 0.01
	C	-1.32 ^{d,A} $\pm$ 0.01	-1.68 ^{e,A} $\pm$ 0.01	1.78 ^{c,A} $\pm$ 0.07	2.27 ^{b,AB} $\pm$ 0.01	2.90 ^{a,A} $\pm$ 0.01
	PC	-1.35 ^{d,A} $\pm$ 0.01	-1.72 ^{e,A} $\pm$ 0.01	2.09 ^{c,A} $\pm$ 0.01	2.37 ^{a,A} $\pm$ 0.02	2.26 ^{b,C} $\pm$ 0.01
	N	8.23 ^{a,D} $\pm$ 0.02	8.08 ^{b,E} $\pm$ 0.05	6.89 ^{c,E} $\pm$ 0.01	4.86 ^{d,D} $\pm$ 0.05	4.55 ^{e,D} $\pm$ 0.01
	Pro	8.41 ^{b,C} $\pm$ 0.01	8.57 ^{a,C} $\pm$ 0.07	6.94 ^{c,D} $\pm$ 0.01	4.51 ^{e,C} $\pm$ 0.03	4.85 ^{d,C} $\pm$ 0.01
b^*	Pre	8.30 ^{b,D} $\pm$ 0.03	8.40 ^{a,D} $\pm$ 0.03	7.56 ^{c,B} $\pm$ 0.03	4.92 ^{d,DB} $\pm$ 0.01	4.96 ^{d,C} $\pm$ 0.03
	S	8.50 ^{b,B} $\pm$ 0.03	8.80 ^{a,B} $\pm$ 0.04	7.09 ^{c,C} $\pm$ 0.02	4.97 ^{e,B} $\pm$ 0.02	5.22 ^{d,B} $\pm$ 0.04
	C	10.32 ^{a,A} $\pm$ 0.01	10.15 ^{a,A} $\pm$ 0.03	8.76 ^{b,A} $\pm$ 0.02	7.38 ^{d,A} $\pm$ 0.02	7.40 ^{c,A} $\pm$ 0.14
	PC	10.32 ^{a,A} $\pm$ 0.01	10.17 ^{b,A} $\pm$ 0.01	8.55 ^{c,A} $\pm$ 0.02	7.09 ^{d,A} $\pm$ 0.01	7.11 ^{d,A} $\pm$ 0.01

^{a-f}Different lowercase superscripts indicate significant differences among storage times, $P < 0.05$.

^{A-F}Different uppercase superscripts indicate significant differences among goat milk yogurts, $P < 0.05$.

¹Measured L^* , a^* , and b^* values were used as indicators of lightness (L^*), redness (a^*), and yellowness (b^*).

²N = natural; Pro = probiotic; Pre = prebiotic; S = synbiotic; C = cupuassu; PC = probiotic with cupuassu.

et al., 2005), and wheat bran (Hashim et al., 2009). The b^* values decreased significantly in all yogurts (N, Pro, Pre, S, C, and PC) during the 28 d of refrigerated storage ($P < 0.05$).

These results (increased a^* and decreased b^*) indicate that the reddish color was reinforced, which should be attributed to the goat milk, due to carotenoids (Noziere et al., 2006) and lipid oxidation (Xia et al., 2012), because all the yogurts exhibited the same behavior. Statistical analyses demonstrated that, although the pattern was the same, the treatments with and without cupuassu pulp differed ($P < 0.05$). Other studies have presented the same performance (increased a^* and decreased b^*) when fruit (pomegranate) and vegetal (yam) ingredients were added to yogurt (Kim et al., 2011; Trigueros et al., 2014).

Apparent Viscosity Analysis

The effects of addition of a probiotic, a prebiotic, and cupuassu pulp on the apparent viscosity of the goat milk yogurts (N, Pro, Pre, S, C, and PC) during storage are presented in Figure 2. On the initial day, the viscosities of the Pre, S, C, and PC yogurts were higher than N goat milk ($P < 0.05$; i.e., the addition of

cupuassu pulp and inulin increased the apparent viscosity). The addition of inulin may increase the structure of dairy products, which can change the viscosity and rheological properties of dairy foods. Also, it can be technologically used as a fat substitute (Paseephol et al., 2008). The cupuassu pulp has a particular chemical composition, being rich in fiber (mainly soluble fiber) and containing a considerable amount of starch as well as pectin polysaccharides (Vriesmann et al., 2009), which could improve the apparent viscosity of C and PC yogurts.

Regarding the period of storage, the apparent viscosity remained constant until d 7 of storage, in all goat milk yogurts, and then decreased ($P < 0.05$). The decrease in apparent viscosity might have been caused by the whey separation with increasing storage time (Al Mijan et al., 2014). This behavior is in agreement with the results of Wang et al. (2012), who compared the apparent viscosity of goat and cow milk yogurts.

The development of apparent viscosity in yogurts is associated with the aggregation of casein micelles and gel formation, which is a consequence of biochemical and physicochemical changes during fermentation of milk (Gaygadzhiev et al., 2009; Singh and Kim, 2009). The apparent viscosity also increases as the pH of

Figure 2. Apparent viscosity of the natural (N), probiotic (Pro), prebiotic (Pre), synbiotic (S), cupuassu (C), and probiotic with cupuassu (PC) goat milk yogurts during 28 d of refrigerated storage. Different uppercase letters (A–C) indicate significant differences among goat milk yogurts, $P < 0.05$; different lowercase letters (a, b) indicate significant differences among storage times, $P < 0.05$.

Table 3. Firmness, consistency, and cohesiveness values (means $\pm$ standard deviation) of goat milk yogurts measured at 4°C during the storage period

TPA ¹ parameter	Treatment ²	Storage period (d)				
		0	7	14	21	28
Firmness (g)	N	22.28 ^{a,B} $\pm$ 0.12	21.42 ^{a,A} $\pm$ 0.20	20.81 ^{a,A} $\pm$ 0.13	21.27 ^{a,A} $\pm$ 0.18	20.70 ^{a,AB} $\pm$ 0.11
	Pro	22.32 ^{a,B} $\pm$ 0.11	21.85 ^{a,A} $\pm$ 0.06	20.52 ^{ab,A} $\pm$ 0.28	19.30 ^{ab,A} $\pm$ 0.62	17.57 ^{b,B} $\pm$ 0.12
	Pre	21.92 ^{a,B} $\pm$ 0.21	22.81 ^{a,A} $\pm$ 0.47	21.41 ^{a,A} $\pm$ 0.17	21.17 ^{a,A} $\pm$ 0.14	21.45 ^{a,A} $\pm$ 0.32
	S	22.14 ^{b,A} $\pm$ 0.16	21.59 ^{a,A} $\pm$ 0.11	20.52 ^{a,A} $\pm$ 0.28	21.59 ^{a,A} $\pm$ 0.31	20.16 ^{a,AB} $\pm$ 0.02
	C	21.85 ^{ab} $\pm$ 0.23	21.88 ^{a,A} $\pm$ 0.02	21.78 ^{a,A} $\pm$ 0.35	20.88 ^{a,A} $\pm$ 0.02	20.73 ^{a,AB} $\pm$ 0.12
	PC	26.16 ^{a,A} $\pm$ 0.52	21.45 ^{b,A} $\pm$ 0.18	21.42 ^{b,A} $\pm$ 0.17	20.73 ^{b,A} $\pm$ 0.03	20.88 ^{b,AB} $\pm$ 0.16
Consistency (g/s)	N	122.86 ^{a,AB} $\pm$ 0.15	121.27 ^{a,A} $\pm$ 0.01	122.50 ^{ab,B} $\pm$ 0.08	123.23 ^{a,A} $\pm$ 0.07	118.14 ^{a,B} $\pm$ 0.19
	Pro	126.92 ^{a,B} $\pm$ 0.13	121.77 ^{a,A} $\pm$ 0.20	118.69 ^{ab,B} $\pm$ 0.17	103.22 ^{b,A} $\pm$ 0.19	98.07 ^{b,B} $\pm$ 0.16
	Pre	121.31 ^{a,AB} $\pm$ 0.44	126.43 ^{a,A} $\pm$ 0.30	125.98 ^{a,AB} $\pm$ 0.32	127.23 ^{a,A} $\pm$ 0.05	127.30 ^{a,A} $\pm$ 0.31
	S	120.12 ^{a,AB} $\pm$ 0.29	117.63 ^{a,A} $\pm$ 0.16	115.34 ^{b,B} $\pm$ 0.43	113.96 ^{a,A} $\pm$ 0.06	123.13 ^{a,A} $\pm$ 0.06
	C	122.09 ^{a,AB} $\pm$ 0.12	122.18 ^{a,A} $\pm$ 0.05	124.25 ^{a,A} $\pm$ 0.21	123.55 ^{a,A} $\pm$ 0.10	122.46 ^{a,B} $\pm$ 0.20
	PC	127.29 ^{a,A} $\pm$ 0.67	122.46 ^{a,A} $\pm$ 0.31	120.56 ^{ab,B} $\pm$ 0.04	120.25 ^{a,A} $\pm$ 0.11	122.6 ^{a,B} $\pm$ 0.14
Cohesiveness (g)	N	-30.29 ^{a,AB} $\pm$ 0.16	-31.48 ^{a,A} $\pm$ 0.32	-30.54 ^{a,A} $\pm$ 0.25	-30.72 ^{a,A} $\pm$ 0.55	-30.97 ^{a,A} $\pm$ 0.05
	Pro	-32.45 ^{a,B} $\pm$ 0.65	-30.29 ^{a,A} $\pm$ 0.11	-31.55 ^{a,A} $\pm$ 0.10	-29.75 ^{a,A} $\pm$ 0.48	-29.83 ^{a,A} $\pm$ 0.04
	Pre	-29.75 ^{a,AB} $\pm$ 0.53	-30.58 ^{a,A} $\pm$ 0.57	-30.79 ^{a,A} $\pm$ 0.30	-31.48 ^{a,A} $\pm$ 0.50	-30.97 ^{a,A} $\pm$ 0.10
	S	-31.84 ^{a,AB} $\pm$ 0.50	-29.36 ^{a,A} $\pm$ 0.32	-31.30 ^{a,A} $\pm$ 0.50	-30.87 ^{a,A} $\pm$ 0.55	-32.05 ^{a,A} $\pm$ 0.32
	C	-29.75 ^{a,AB} $\pm$ 0.17	-30.87 ^{a,A} $\pm$ 0.50	-31.04 ^{a,A} $\pm$ 0.10	-31.08 ^{a,A} $\pm$ 0.15	-32.23 ^{a,A} $\pm$ 0.30
	PC	-29.39 ^{a,A} $\pm$ 0.54	-29.76 ^{a,A} $\pm$ 0.10	-29.86 ^{a,A} $\pm$ 0.16	-31.73 ^{a,A} $\pm$ 0.10	-28.89 ^{a,A} $\pm$ 0.16

^{a,b}Different lowercase superscripts indicate significant differences among storage times, $P < 0.05$.

^{A,B}Different uppercase superscripts indicate significant differences among goat milk yogurts, $P < 0.05$.

¹TPA = texture profile analysis.

²N = natural; Pro = probiotic; Pre = prebiotic; S = synbiotic; C = cupuassu; PC = probiotic with cupuassu.

milk decreases, which is attributable to the additional swelling of casein micelles. At pH 5.4 to 5.3, the initial increase of apparent viscosity can be observed, at this stage indicating the initiation of aggregation. In the pH range of 5.1 to 4.6, the apparent viscosity of goat products increases (Park, 2007), which typically occurs in yogurts. In our study, this increase on apparent viscosity effect by pH happened in all treatments (N, Pro, Pre, S, C, and PC).

However, the casein micelles of goat milk contain more calcium, inorganic phosphorus, and noncentrifugal casein, and are less solvated, less heat stable, and lose β -casein more readily than bovine casein micelles (Park et al., 2007). This fact is related to the large difference in the apparent viscosity of yogurt made with goat milk compared with cow milk.

Instrumental Texture Analysis

The TPA parameters well represented the yogurt textural characteristics. Firmness, consistency, and cohesiveness are commonly evaluated in determining yogurt texture (Espírito Santo et al., 2012; Buriti et al., 2014; Ilić et al., 2014). Different goat milk yogurts were measured, as presented in Table 3.

Gel formation is one of the main texture properties of yogurt. This structure is result of casein aggregation by pH decreasing and disulfide bonding between κ -casein and denatured whey proteins (Damin et al., 2009). In addition, other parameters, such as milk base compo-

sition, heat treatment applied, fermentation process, storage conditions, and starter culture, also perform a determinative role in gel structure formation (Akalin et al., 2012).

Regarding firmness, no statistical difference ($P > 0.05$) was found between the treatments. The firmness decreased in all yogurts (N, Pro, Pre, S, C, and PC) during 28 d of storage (Table 3). However, despite similar behavior in the different treatments, this decline was statistically significant ($P < 0.05$) only in the PC yogurt. Therefore, the addition of each ingredient (cupuassu pulp and probiotic) separately did not affect the firmness, although together, they changed this parameter. Oliveira et al. (2001) reported that the firmness of fermented milks is highly dependent on the culture composition, TS, and protein content of the product. Moreover, the type of protein and the interaction between the ingredients used and the composition of the culture can affect the firmness of the product (Oliveira et al., 2001). This fact may explain the significant decline in the yogurt PC, which has lower lactic protein content when compared with other treatments. The firmness of yogurts is also related to the bacteria *L. delbrueckii* ssp. *bulgaricus*. The incorporation of this microorganism into the yogurt starter culture improved the firmness, which in general is due to the attachment of mucogenic strains to the protein matrix via the exopolysaccharides (Shihata and Shah, 2002).

The consistency of the samples was significantly high ($P < 0.05$) in the yogurts with added prebiotic (Pre and

S) compared with the others (N, Pro, C, and PC) at the end of storage (d 28). Furthermore, the consistency of the Pre and S goat milk yogurt remained constant ($P > 0.05$) during the storage period (Table 3). A similar result was obtained for the yogurt consistency with the addition of the inulin (Pimentel et al., 2012, 2013). This prebiotic helped to increase this physical property, but up to a certain concentration. The interactions between whey proteins and κ -casein make the micelles less sensitive to the pH decline, increasing their solubility. Inulin is a soluble fiber and a water-structuring agent. In addition, this prebiotic can form complexes with the protein aggregates, and it must be part of the structural network that is formed during fermentation and structuring of the stirred yogurt (Srisuvor et al., 2013).

The cohesiveness values indicated that the predominance of protein in the composition of the yogurt caused the large number of casein–casein linkages broken during stress application to reform after the stress was released (Peng et al., 2009). The cohesiveness values are provided in Table 3. In this study, the cohesiveness in all treatments remained constant ($P > 0.05$) during refrigeration storage. Therefore, the addition of the cupuassu pulp, probiotic, and prebiotic did not affect the cohesiveness. Hence, cohesiveness should not be considered a good parameter because all treatments showed the same results. The cohesiveness value together with the springiness may indicate a predominance of protein in the composition of the yogurt, which led to a large promoted number of broken casein–casein linkages during stress application, which reformed after the stress was released (Sandoval-Castilla et al., 2004). A possible explanation for the similar behavior of this parameter in all yogurts is that they have a proximate milk protein content.

CONCLUSIONS

We conclude that cupuassu pulp is potentially useful in the manufacture of goat milk yogurts to improve their texture. In this way, cupuassu is an important technological strategy for the dairy goat industry.

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