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Rheological, physical, and sensory evaluation of low-fat cupuassu goat milk yogurts supplemented with fat replacers

ABSTRACT

The use of skim milk is a strategy to increase goat milk yogurt acceptability. However, it can negatively affect yogurt rheology because fat plays a vital role in dairy structural integrity. Thus, this study aimed to investigate the effects of fat replacers on the rheological, physical, and sensory parameters of low-fat cupuassu goat milk yogurts during refrigerated storage (28 days). Five goat milk yogurts formulations were carried out: whole yogurt (WY), skim yogurt (SY), skim yogurt with inulin (SIY), skim yogurt with maltodextrin (SMY), and skim yogurt with whey protein (SWY). Treatments were subjected to bacterial counts, chemical composition, pH, water holding capacity, instrumental color and texture, rheological and sensory analyses. All samples showed reducing pH values, water holding capacity, *L**, and *b** during storage. Regarding texture, the firmness and consistency decreased during storage. On the other hand, the viscosity index significantly increased during refrigerated storage time. Moreover, all treatments exhibited viscoelastic behaviour. In addition, SIY and SMY showed the highest apparent viscosity. Furthermore, SIY, SMY, and SWY formulations exhibited positive sensory scores for appearance, color, aroma, texture, and viscosity. However, the overall acceptability and purchase intention did not differ statistically between WY and the fat-replacement treatments (SIY, SMY, and SWY). These results indicate that fat substitutes improved the quality of skimmed formulations. Thus, inulin and maltodextrin have the potential as functional fat replaces to produce low-fat goat milk yogurts.

Keywords: Inulin, maltodextrin, whey protein, rheological analysis, sensory acceptance.

INTRODUCTION

Fermented dairy foods benefit human consumption due to bioactive compounds (Vieira et al., 2015). Essentially, goat milk yogurt presents high digestibility and high nutritional value. However, as previously reported, this variety of yogurt shows lower overall acceptance by the unusual consumer (Costa et al., 2014) than cow milk yogurt (Costa et al., 2015). For instance, goat milk yogurt presents a delicate texture and a fragile gel structure, affecting consumer preference and product acceptability. The lesser acceptance also happens due to the goat milk fat composition, attributed to a high content of short-chain fatty acids, such as caproic, caprylic, and capric acids, which gives an unpleasant "goaty" taste the product (Ceballos et al., 2009). As texture and flavor are attributes that significantly influence consumer acceptance, the substitution of goat milk fat, together with the addition of a polysaccharide-rich flavoring agent, as cupuassu pulp, can improve both the taste and texture of goat milk yogurts (Costa et al., 2015; 2017).

Nevertheless, because milk fat is one of the responsible compounds for the structural integrity of yogurts (Zhang et al., 2015; Grossmann et al., 2021), the production of low-fat goat milk yogurts can negatively affect the physicochemical, rheological, and textural characteristics of these products. Furthermore, the development of low-fat yogurts without changing their sensory and techno-functional properties has been a challenge for the dairy industry. One alternative can be the addition of fat replacers, like inulin, maltodextrin, and whey protein (Costa et al. 2016a; Salgado et al. 2020). Among the most studied fat substitutes, inulin stands out for its prebiotic potential (Costa et al., 2015; Costa et al., 2016a; Delgado et al., 2017), and maltodextrin and whey proteins are known for their role in dietary supplementation by promoting energy increase and muscle growth, respectively (Bronkhorst et al., 2014; Master et al., 2021).

Moreover, the cupuassu (*Theobroma grandiflorum*) is a native tropical fruit to the Brazilian Amazon Rainforest. The cupuassu pulp has a distinctive flavor, which, together with a sensory strategy, can increase the acceptance of goat milk yogurts (Costa et al., 2017). Regarding its chemical composition, the cupuassu pulp is rich in fibers and has a considerable amount of starch and pectin polysaccharides. Therefore, the fruit pulp addition can also improve yogurts' textural and rheological properties (Costa et al., 2015; Kermiche et al., 2018). Besides, fruit pulp addition is a viable technology alternative to produce goat milk yogurts aiming to reduce the "goaty" flavor (Senaka Ranadheera et al., 2012; Costa et al., 2016; 2017).

However, further studies should be carried out to assess the impact of this substitution on goat milk yogurt throughout storage. In this context, the major original hypothesis was that fat replacers improve physical and sensory properties of low-fat cupuassu goat milk yogurts during storage. Thus, this study aimed to monitor the effects of fat replacers (inulin, maltodextrin, and whey protein) on chemical composition, pH, water holding capacity, color, textural, and rheological proprieties of low-fat cupuassu goat milk yogurts during the storage period (0, 7, 14, 21, and 28 days) at 4 ℃. Sensory acceptance was also performed to assess the consumer acceptability of these new products.

MATERIAL AND METHODS

Production of goat milk yogurts

Cupuassu goat milk yogurts (n = 3) were prepared as described by Costa et al. (2016a).

In all treatments, thermophilic yogurt cultures (1% vol/vol; YF-L903®, Chr. Hansen, Valinhos, Brazil) and cupuassu pulp (10% w/vol; Polpa de Fruta®, Macapá, AP, Brazil) were added in UHT whole or skimmed goat milk (Caprilat®, Paraná, Brazil). Inulin (5% w/vol; Ingredients & Systems Biotechnology®, São Paulo, SP, Brazil), maltodextrin (5% w/vol; Max Titanium®, São Paulo, SP, Brazil) and whey protein isolate (5% w/vol; Optimum Nutrition®, Meridian Lake, Aurora, USA) were added depending on the treatment. Five treatments of cupuassu goat milk yogurts were performed: whole (WY), skimmed (SY), skimmed with inulin (SIY), skimmed with maltodextrin (SMY), and skimmed with whey protein (SWY). All ingredients were added before fermentation, and the samples were fermented in an oven at 43 ± 1 °C. The fermentation was interrupted when the pH reached 4.5. Finally, the product was stored at 4 ± 1 °C for 28 days. All analyses were performed in analytical and experimental triplicate. Physicochemical, textural, and rheological analyses were done during storage (0, 7, 14, 21, and 28 days).

Proximate composition

The cupuassu goat milk yogurts were analyzed for fat content by the Gerber method, protein by the Kjeldahl method using a conversion factor of 6·38, moisture by oven drying, and ash determination by weight loss of material subjected to muffle (AOAC, 2012).

pH, water holding capacity, instrumental color, and texture

The cupuassu goat milk yogurts were analyzed for pH by a digital potentiometer (model

PG1800, Cap Lab, SP, Brazil). Before use, the electrode was calibrated with standard buffer solutions of pH 4.00 and 7.00.

Water holding capacity (WHC) was determined using the centrifugation method described by Feng et al. (2019). Briefly, the samples (10g) were centrifuged at 1500 *g* for 10 min after coagulation formation. The supernatant was drained, and the remaining pellets were weighted.

Color determinations (L^*, a^*, and b^*) were made at 5 ℃ using a Minolta CM-600D spectrophotometer (Minolta Camera Co., Osaka, Japan) for 28 days of storage (Costa et al., 2015).

Firmness (*g*), consistency (g.sec), cohesiveness (g), and index of viscosity (g.sec) were measured using a texture analyzer (TA-XT.Plus, Stable Micro Systems Ltd., Surrey, UK) equipped with a 49.0 N load cell, which was calculated using the software Exponent version 6.1.9.1 (Stable Micro Systems, Surrey, England). The back-extrusion cell plunger was 3.6 cm in diameter and set at 20 mm above the sample surface. The test cell penetrated 2 cm into the sample (300 mL) at 5 ℃ (Costa et al., 2016a).

Rheological analysis

The rheological measurements were determined using a Brookfield concentric cylinder viscometer (LVDVIII, Brookfield Engineering Laboratories Inc., Stoughton, MA, USA). The measurements were carried out in triplicate using a spindle 67 at 5 ℃ on days 0, 7, 14, 21, and 28. The flow curves were generated by a linearly increased 2 to 150 rpm (2, 6, 10, 20, 40, 60, 80, 100, 120, and 150). Their corresponding shear rates (γ) and shear stresses (σ) were computed from those relations given by the instrument manufacturer and then recorded (Vieira et al., 2019). Thixotropy response was not analyzed. The rheological properties were fitted with the Herschel-Bulkley model (Eq. 1). This model is the best to describe the rheological behavior of yogurts (Behnia et al., 2013).

$$\sigma = \sigma_\circ + K\gamma^n \qquad \text{(Eq. 1)}$$

Where σ is the shear stress (Pa), $\sigma_\circ$ is the yield stress (Pa), γ is the shear rate (s^{-1}), *K* is the consistency index (mPa. s^n), and *n* is the flow behavior index (dimensionless). The Wingather program (Brookfield Engineering Laboratories Inc., Stoughton, MA, USA) was used to collect the data and calculate apparent viscosities. Viscosity values in the upward curves at a rate of 60 rpm were considered the apparent viscosity (mPa s) of the yogurts samples (Costa et al., 2015; 2017).

Sensory acceptance

The test session was performed on day 7 of storage. One hundred and nineteen untrained participants (72 women, 47 men) ranging from 19 to 63 years old (mean = 24, SD = 8) were recruited. The inclusion criterion was the regular consumption of dairy products. People with allergies or intolerance to dairy products were not recruited. All participants signed the Informed Consent Form. This study has the approval of the Research Ethics Committee (CEP UFF - Hospital Universitário Antônio Pedro/ Faculdade de Medicina da Universidade Federal Fluminense) under the number CAAE 11527113.8.0000.5243.

The participants performed independent observations on randomized samples of yogurt. Sensory attributes of foods detectable by human senses are often used to evaluate yogurt quality. The panelists evaluated the appearance, color, aroma, flavor, texture, viscosity and overall acceptability of each sample based on a 9-point category scale (1 = extremely dislike to 9 = extremely like). Additionally, purchase intention was evaluated using a 5-point scale ranging from 1 = definitely would not buy to 5 = definitely would buy.

The sensory attributes used in this study were explained to participants. Appearance is evaluated through hedonic tests to assess the overall liking and degree of liking for individual sensory attributes. This attribute encompasses all visually perceptible sensory impressions of a food. Color is the evaluation of yogurt color (white, whitish, yellow, or yellowish). Aroma is the identification of characteristic smell. Flavor is the general evaluation of flavor and identification of any defects. The texture is the evaluation of gel fragility, hardness, gelatinous or gumminess structure. Viscosity is the force required to move the spoon back and forth (panelists evaluated gel viscosity by stirring the yogurt sample with a spoon). Overall acceptability is the overall yogurt rating, an average of all attributes together.

Statistical analysis

Data were reported as mean ± standard deviation (n = 3). One-way ANOVA analyzed for proximate composition and sensory results, and two-way ANOVA for all other data. When a significant F ($P < 0.05$) was observed, the data were subjected to Tukey's multiple comparison test at two-side $P < 0.05$. All statistical analyses were performed using XLSTAT version 2013.2.03 (Addinsoft, Paris, France).

RESULTS AND DISCUSSIONS

Proximate composition of cupuassu goat milk yogurts

The chemical composition of cupuassu goat milk yogurts is presented in Table 1. SY, SIY, SMY, and SWY treatments had lower (P < 0.05) fat content values than WY (3.12±0.25). These results are appropriated since WY had no reduction in fat content, being elaborated from whole milk. SWY had higher (P < 0·05) protein content (5.02±1.69) than the other treatments (WY, SY, SIY, and SMY). In this treatment (SWY), the milk fat was replaced by whey protein, which explains this difference in the percentage of proteins. Regarding moisture and ash content, there was no difference between treatments.

pH determination

The SWY presented an initial pH value of 4.61±0.02, which was higher (P < 0.05) than the other treatments (WY, SY, SIY, and SMY) until the 21st day of the storage period (Table 2). This behaviour can be attributed to the buffering capacity of whey proteins, which difficult the lowering pH of milk during fermentation and storage (Salaün et al., 2005).

During storage time, all treatments presented a decrease (P < 0.05) in pH, compared to the initial value (day 0), for example WY ranged from 4.46±0.02 to 4.34±0.06. This reduction in pH suggests the occurrence of post-acidification, which is probably attributed to *Lactobacillus delbrueckii* ssp *bulgaricus* biosynthesis of lactic acid and hydrogen peroxide during the refrigerated storage. Consistently, when the sugar sources are scarce, microorganisms start to consume proteins and fatty acids as carbon sources, producing other metabolites (Costa et al., 2015). Kermiche et al. (2018) also observed a decrease in pH through the storage period in yogurts with cantaloupe pulp incorporation. These authors also associated the reduction in pH with the formation of catabolites derived from microorganisms' metabolization of yogurt protein sources, which decreased the pH of the final products.

Water holding capacity

The water holding capacity results are exhibited in Table 2. The treatment with maltodextrin addition (SMY) presented a similar result to the whole yogurt treatment (64.87±0.57 and 64.38±1.25, respectively). Maltodextrin is a white powder made from corn, rice, potato starch, or wheat, generally used as a thickener or filler to increase the volume of processed foods. According to Cheng et al. (2020), the functionality of maltodextrins as fat replacers is slightly different than native or modified starch because maltodextrins are hydrolyzed products and therefore do not have a globular structure. However, the strong water holding capacity of maltodextrins gives it the ability to form gels with water in food systems. This fact explains as maltodextrin contributed positively to the formation of the yogurt gel, improving the water retention capacity of cupuassu goat milk yogurt.

During the storage period, the WHC sharply dropped on the first 7 days, gradually decreasing in all treatments afterward. The water holding capacity of yogurt is mainly affected by total solids. The results were consistent with the previous results reported by Machado et al. (2017), Silva et al. (2017), and Feng et al. (2019).

Instrumental color

The color changes in cupuassu goat milk yogurts during storage time are exhibited in Table 3. The L^* values were affected (P < 0.05) by the skimmed milk formulations (SY, SIY, SMY, and SWY), whereas the whole yogurt presented values between 81.66±0.16 and 82.09±0.21, and the skimmed varieties ranged from 78.79±0.53 to 71.75±0.41. This behavior in L^* value indicates that the fat content directly influences the lightness attribute. The whiteness in yogurts results from the colloidal particles in milk, including the fat globules. Thus, the significant fat content decrease in skimmed milk reduces light in the visible spectrum, making the skimmed formulationsdarker (lower L^* value). A preliminary study with inulin, maltodextrin, and whey protein also described an increase in gel opacity (Costa et al., 2016a; González-Martınez et al., 2002), which also contributed to L^* values decrease in these treatments. The yogurt with whey protein (SWY) was the treatment that presented the lowest L^* value. The increase of milk protein content in dairy foods, such as after whey protein addition, elevates the total protein acidic groups, resulting in better coagulation. The protein coagulation, however, affects the ratio reflected: absorbed light, leading to a reduced perception of lightness (Teba et al., 2017). On the other hand, SMY and SIY presented slightly lower L^* values than WY. As for the storage period, this parameter decreased slightly, in all treatments, throughout the refrigerated storage.

The cupuassu goat milk yogurts presented a green color (a^*), attributed to the natural pigments of cupuassu pulp (Costa et al., 2015). The fat content influenced a* perception, whereas the WY yogurt demonstrated the lowest ($P < 0.05$) a^* value compared to the skimmed milk treatments (SY, SIY, SMY, and SWY) (Table 1). Because the fat globules on the whole milk surface reflect all wavelengths, less light is absorbed by the green compounds, such as riboflavin, which results in a minor perception of the green color (Cheng et al., 2019). Among the treatments with fat replacers, the yogurt with whey protein (SWY) presented the lowest a^* value (-1.36±0.02) and demonstrated a similar behavior to the whole yogurt (-0.99±0.02). Consistently, less greenness has been reported to indicate higher protein content (Costa et al., 2016a; Teba et al., 2017). In general, regarding the storage time, the treatments presented a decrease in this parameter, indicating a reduction in the greenness of the cupuassu goat milk yogurts. This behavior can be related to changes in yogurt structure, such as gel stirring and acidity, resulting in a leakage of natural pigments from the yogurt matrix (Costa et al., 2015).

The *b** values were different in all treatments, and the SY yogurt was less yellow (7.80±0.10) than the other treatments (ranging from 8.27±0.17 to 12.23±0.12). Similar observations were described by Costa et al. (2015; 2016a; 2017), studying goat milk yogurts with cupuassu pulp. Moreover, the results indicate that maltodextrin and whey protein increased the light reflectance responsible for the yellow color, thereby*b** values were similar (SMY) and higher (SWY), to the whole yogurt (WY). Consistently, the addition of whey protein has been described to provide a more yellowish color to yogurt (González-Martınez et al., 2002), which can explain the highest yellowness attribute in SWY yogurt among the treatments. As well as the other parameters, *b** values also presented a decrease in storage period in all treatments. An increase in *b** values is described as typical of non-enzymatic browning (Maillard) reactions during storage (Costa et al., 2015; García-Pérez et al., 2005). The reduction of *b** values herein can be attributed to cupuassu pulp, which has antioxidant activity (Costa et al., 2017).

Instrumental texture

Texture parameters are presented in Table 4. On the first day of storage, SIY and SMY presented firmness values between 37.79±2.03 and 42.11±1.96, respectively, while WY and SY showed lower results (33.34±0.87 and 33.08±0.76, respectively. Thus, the skimmed goat milk yogurts with inulin and maltodextrin presented higher firmness (P < 0.05) than controls treatments (WY and SY) (Table 4). Therefore, the increase in total solids (after inulin and maltodextrin addition) contributed to gel structure formation, explaining this behavior. However, results indicate that only inulin (SIY) maintained a higher firmness than controls over storage time (up to 21 days), there being no difference among treatments in 28 days.

For consistency, only maltodextrin (SMY) maintained higher values than controls, both on the first and last days of storage. There was no difference in texture among treatments on the other analyzed days. This pattern can be attributed to the fact that the ingredient type and the interaction among them also affected the gel structure formation. Nonetheless, the inulin, maltodextrin, and whey protein, significantly altered the yogurts' cohesion, which was lower (P > 0.05) (-7.24±0.36, -6.98±0.23, and -6.49±0.25, respectively) than the treatments without fat substitutes, WY and SY (-5.66±0.44 and -5.36±0.53, respectively) (Table 4). These fat replacers may affect the cohesiveness due to the mixed protein network between casein micelles and them, involving the disulphide bond formation (Costa et al., 2015; Santillán-Urquiza et al., 2017).

There was no difference (P < 0.05) regarding the viscosity index on the first day of storage in any treatments. . Consistently, previous studies reported that protein is the most important compound responsible for affecting yogurt texture properties, and the role of fat is of secondary importance (Pakseresht et al., 2017). However, skimmed yogurt with inulin was the treatment that most improved viscosity, presenting higher values than controls from 7 to 28 days of storage (Table 4). SMY was the second more effective treatment, increasing the viscosities in 7, 21, and 28 days. Indeed, the increase of total solids is reported as a factor responsible for improving the viscosity of yogurts (Pakseresht et al., 2017). Compared to SY, the skimmed yogurt with whey protein showed a low ability to increase the viscosity, presenting similar values from days 7 to 21 and a slightly higher increase on day 28. Consistently, a decrease in gel viscosity with an increasing whey protein-to-casein ratio was reported by Puvanenthiran et al. (2002).

The viscosity index of the low-fat cupuassu goat milk yogurts with fat substitutes varied during the 28 days of storage (Table 4), and there was a significant difference between the sampling periods for these products (P < 0.05). These treatments considerably reduced their viscosity values from day 0 to day 28 (P < 0.05), indicating that fat substitutes lose their efficiency to maintain the viscosity as the storage time increases.

Storage time, firmness, consistency, and viscosity index decreased in all treatments regardless of the presence/absence of fat substitutes. In the same way as the present study, Costa et al., (2015) and Santillán-Urquiza et al. (2017) also observed a significant decrease in the textural parameters of yogurts. This reduction may be due to changes in the coefficient of consistency by these compounds during storage. On the other hand, cohesion increased for WY, SIY, SMY, and SWY over storage (Table 4), which agrees with reducing firmness and consistency (Gauche et al., 2009).

Apparent viscosity

The whole yogurt presented higher apparent viscosity than skim yogurt only at the end of the storage (two last weeks) (Table 5). Consistently, this result indicates that fat is relevant for maintaining apparent viscosity throughout storage. SIY and SMY yogurts presented a higher apparent viscosity (P < 0.05), superior to the whole control (WY) and other skimmed (SY and SWY) treatments (Table 5) during the entire storage. These behaviors result from casein micelle aggregation with fat substitute compounds during the fermentation process (Costa et al., 2016b). The inulin can increase the molar mass of the product, increasing viscosity. Moreover, maltodextrin has also been described to improve yogurt viscosity (Delgado et al., 2017). Thus, inulin and maltodextrin can increase the apparent viscosity of goat milk yogurts.

However, whey protein addition reduced viscosity levels compared to controls (WY and SY) for almost all storage (days 7, 14, and 28). On the day 21, although SWY presented improved viscosity compared to skim yogurt, its viscosity value remained below WY. On fresh yogurt (day 0), there was no difference among treatments with whey protein and controls (WY and SY). Whey protein can negatively affect the interaction among casein micelles, which decreases the gel viscosity (Puvanenthiran et al., 2002) and the visco-elastic properties of yogurt (Guggisberg et al., 2007; 2009). Hence, in this study, whey protein alone was not enough to improve the apparent viscosity of fresh goat milk. On the other hand, the apparent viscosity decreased ($P < 0.05$) considerably during storage in all treatments. This decrease is related to syneresis increase and can be caused by the whey separation during storage time (Costa et al., 2015).

Rheological analyses

During the storage period, the low-fat cupuassu goat milk yogurts were fitted to Herschel-Bulkley model (Table 5). In all treatments, the determination coefficients for the fitted model were ≥ 0.99. Therefore, the model was suitable to study the rheological properties of yogurts. Apparent viscosities decreased with increasing shear rate during shearing, while shear stress increased as a function of shear rate for all samples (data not showed). Therefore, all treatments exhibit a rheological profile as a non-Newtonian liquid with viscoelastic behaviour. Hence, the observed results imply that treatments with fat substitutes did not considerably influence the flow type of samples, which remained typical of yogurt. The flow behavior depends on milk concentration, composition and pre-treatment, starter culture, and fermentation condition (Zhang et al., 2015).

Different curves (apparent viscosity vs. shear rate; shear stress vs. shear rate) were noted depending on the storage time. However, the SY had lower shear stress values than fat-substitutes treatments (SIY and SMY) independent of the storage period. Indeed, this behavior is consistent with the improved apparent viscosity profiles observed for treatments with these fat substitutes. The addition of inulin and maltodextrin (SIY and SMY) increased the apparent viscosity, and consequently, the shear stability (the profile does not change over the storage time). However, whey protein addition decreased the apparent viscosity for the shear. This finding implies that the fat substitute type influences the shear rate. Despite that, more studies are needed to explain the shear rate behavior due to the fat-substituents addition.

Yield stress (**σ_0**) is described as the minimum stress value to detect material deformation (Behnia et al., 2013). WY presented higher yield stress than skimmed yogurt during the storage period. Whole yogurt microscopy shows a slightly more cohesive and less coarse network and smaller pores than the low-fat yogurt, contributing to the highest yield stress of whole yogurt (Guggisberg et al., 2009). Moreover, treatment with inulin and maltodextrin leads to higher yield stress values than both controls up to 14 days of storage. After, SIY and SMY showed higher yield stress (0.08 and 0.23, respectively) values than skim yogurt (0.02) in 21 days. Finally, on day 28, SMY had higher yield stress compared to all formulations, followed by SWY and SIY, which presented a similar behavior to WY. This result shows that maltodextrin and inulin improved resistance to shear rate compared to the control. Consistently, the yield stress is reported to increase together with the increase of total solids. Thus, the rise of inulin is almost linear for the increase in yield stress values (Guggisberg et al., 2009, 2007). These results also agree with the highest firmness and consistency values found for treatments with inulin and maltodextrin. A positive correlation between yield stress and firmness was previously described in yogurts (Harte et al., 2007).

On the other hand, skimmed yogurt with whey protein (SWY) had a low capacity to increase yield stress, demonstrating similar values to SY for up to 14 days of storage. From the 21st to the 28th day of storage, SWY presented higher values than SY but lower than WY. Consistently, whey proteins negatively influenced the casein network formation in yogurts (Guggisberg et al. 2007), contributing to a weaker gel formation in SWY. Additionally, values of yield stress have changed ($P < 0.05$) with an increase in storage time, with a reduction in all treatments until the last day of storage (Table 3). Proteolytic activity leads to a breakdown of the protein network, resulting in significant decreases in rheological parameters of yogurts during storage (Gandhi & Shah, 2014).

The coefficient of consistency (*K*) indicates the viscosity of the fluid. Their values were consistent with the finding herein for apparent viscosity and viscosity index. The coefficient of consistency, in general, was slightly higher in whole than skim yogurt (Table 3). Therefore, fat content is no significant influence on the coefficient of consistency (Pakseresht et al., 2017). Treatments with inulin and maltodextrin lead to higher coefficients of consistency compared to controls throughout the storage period. The addition of whey protein, however, was ineffective in improving this parameter, resulting in lower values than skimmed yogurt (SY) over storage.

Regarding the storage time, the coefficient of consistency decreased ($P < 0.05$) from the first week to the second. Although it continued to reaseover storage time, the coefficient of consistency reduction was less critical. Further, the observed increase of the coefficient of consistency for treatments SIY and SMY compared to SY can be attributed to the same reasons previously discussed herein, which lead to similar changes in the apparent viscosity and viscosity index of yogurts.

The flow behavior index (n) indicates the degree of non-Newtonian fluid: when “n” is 1, the liquid is Newtonian. If “n” is greater than 1, the fluid is categorized as dilating, and if “n” is between zero and 1, the fluid is classified as pseudoplastic (Behnia et al., 2013). As shown in Table 5, the treatments presented pseudoplastic behavior, except for SWY, which showed dilatant behavior up to 14 days of storage. Therefore, the treatments with inulin and maltodextrin did not change the sample flow, which remained pseudoplastic. Contrastingly, the whey protein changed the rheological behavior from pseudoplastic to Newtonian. The presence of whey greatly influences the rheological behavior of yogurts (Pakseresht et al., 2017). Indeed, whey protein may behave as Newtonian fluid or pseudoplastic depending on the employed concentration. Thus, the whey protein (5%, w/w) promotes the change of pseudoplastic to Newtonian behavior (Dissanayake et al., 2013). Concerning the storage time, the flow behavior index reduced in all treatments with the increasing of storage time. The high proteolytic activity can increase total solids during yogurt storage, contributing to the higher susceptibility to shear thinning (reduction of n) (Elhamid & Elbayoumi, 2017).

Sensory analysis

The acceptance test and purchase intention of treatments are shown in Table 6. SY exhibited the lowest (P < 0.05) score for all tested sensory parameters. The yogurt acceptability is intimately linked to fat content, enhancing these products’ flavor, texture, and appearance. On the other hand, whole milk yogurt and fat substitute compositions

(WY, SIY, SMY, and SWY) exhibited positive appearance, color, aroma, texture, and viscosity values. Also, these formulations exhibited no statistical difference among them for flavor and overall acceptability parameters, demonstrating that the addition of fat substitutes compensated the sensory attributes of the low-fat yogurt formulations. Besides that, SIY and SWY presented higher scores of texture and viscosity compared to SMY. This fact may be explained due to the hydrophilic behavior of maltodextrin, which can affect the flavor and other compounds' solubility, not resembling all sensory properties of fat (Hofman et al., 2016).

Regarding purchase intention (Table 6), excepting SY, no statistical difference was observed among the formulations. Therefore, fat substitutes mimicked the sensory characteristics of fat, which positively affected the consumers' likelihood of purchase intention of skimmed formulations. The low purchase intention score for the samples, in general, is probably associated with a lack of familiarity with cupuassu pulp or the "goaty" flavor (Costa et al., 2014; 2017). Nevertheless, evidence shows that health-oriented consumers, such as athletes, are prone to consume nutrition-modified and functional dairy products for health benefits despite their taste (Costa et al., 2017; Bimbo et al., 2017).

CONCLUSIONS

Inulin and maltodextrin can be used as a technological strategy to produce low-fat cupuassu goat milk, maintaining viscosity and firmness. These results highlight the possible use of inulin and maltodextrin in the dairy industry to develop low-fat goat milk yogurt.

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Table 1. Proximate composition (%) of low-fat cupuassu goat milk yogurts at the beginning of storage (Day 0).

Parameters	**Samples**				
	WY	**SY**	**SIY**	**SMY**	**SWY**
Fat	3.12 ± 0.25^{B}	0.37 ± 0.06^{A}	0.24 ± 0.06^{A}	0.26 ± 0.05^{A}	0.38 ± 0.03^{A}
Protein	2.26 ± 0.70^{A}	2.50 ± 0.21^{A}	2.39 ± 0.18^{A}	2.90 ± 0.47^{A}	5.02 ± 1.69^{B}
Moisture	88.11 ± 0.24^{A}	90.34 ± 0.06^{A}	86.86 ± 0.26^{A}	87.33 ± 0.06^{A}	85.17 ± 0.21^{A}
Ash	0.81 ± 0.09^{A}	0.84 ± 0.03^{A}	0.84 ± 0.01^{A}	0.86 ± 0.05^{A}	0.80 ± 0.02^{A}

WHC – water holding capacity; WY – whole cupuassu goat milk yogurt; SY – skimmed cupuassu goat milk yogurt; SIY – skimmed with inulin cupuassu goat milk yogurt; SMY – skimmed with maltodextrin cupuassu goat milk yogurt; SWY – skimmed with whey protein cupuassu goat milk yogurt.

Values were expressed as a mean ± standard deviation (n = 3).

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

Table 2. pH and water holding capacity (%) of low-fat cupuassu goat milk yogurts during 28 days of refrigerated storage.

Parameters	Sample	Storage time (days)				
		0	7	14	21	28
pH	**WY**	4.46±0.02^{a,A}	4.46±0.02^{a,A}	4.39±0.05^{a,A}	4.36±0.02^{a,AB}	4.34±0.06^{a,A}
	SY	4.45±0.03^{b,AB}	4.41±0.01^{ab,A}	4.34±0.03^{a,A}	4.36±0.01^{a,bA}	4.29±0.03^{a,A}
	SIY	4.52±0.01^{b,AB}	4.47±0.01^{ab,A}	4.44±0.01^{ab,B}	4.50±0.02^{a,bB}	4.40±0.03^{a,A}
	SMY	4.55±0.04^{b,AC}	4.45±0.05^{ab,A}	4.43±0.09^{a,B}	4.48±0.06^{ab,AB}	4.44±0.02^{a,A}
	SWY	4.61±0.02^{c,C}	4.62±0.08^{c,B}	4.53±0.03^{b,C}	4.54±0.05^{b,C}	4.46±0.04^{a,A}
WHC	**WY**	64.38±1.25^{c,C}	61.12±1.02^{b,CD}	61.28±2.23^{b,D}	61.28±1.20^{b,C}	58.77±1.19^{a,B}
	SY	57.09±1.02^{a,A}	57.07±1.70^{a,B}	56.72±0.83^{a,B}	56.56±0.31^{a,B}	54.10±0.74^{a,A}
	SIY	61.50±1.22^{c,B}	57.74±0.68^{b,BC}	58.19±1.06^{b,C}	55.98±0.74^{a,B}	55.75±1.16^{a,A}
	SMY	64.87±0.57^{b,C}	63.58±1.84^{b,D}	63.23±0.95^{ab,C}	62.95±1.05^{ab,C}	59.38±1.02^{a,B}
	SWY	56.17±1.15^{a,A}	53.93±0.42^{a,A}	54.01±1.49^{a,A}	53.68±1.63^{a,A}	54.03±1.44^{a,A}

WHC – water holding capacity; WY – whole cupuassu goat milk yogurt; SY – skimmed cupuassu goat milk yogurt; SIY – skimmed with inulin cupuassu goat milk yogurt; SMY – skimmed with maltodextrin cupuassu goat milk yogurt; SWY – skimmed with whey protein cupuassu goat milk yogurt.

Values were expressed as a mean ± standard deviation (n = 3).

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

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

Table 3. Color parameters values of low-fat cupuassu goat milk yogurts during refrigerated storage.

Parameters	Sample	Storage time (days)				
		0	**7**	**14**	**21**	**28**
L*	**WY**	81.90±0.11$^{b.D}$	82.09±0.21$^{b.D}$	81.97±0.14$^{b.D}$	81.89±0.15$^{b.E}$	81.66±0.16$^{a.E}$
	SY	78.79±0.53$^{b.C}$	78.16±0.37$^{ab.C}$	78.27±0.42$^{ab.C}$	78.28±0.32$^{ab.C}$	77.85±0.67$^{a.C}$
	SIY	77.37±0.14$^{b.B}$	76.21±1.37$^{a.B}$	78.05±0.32$^{b.B}$	78.14±0.14$^{b.C}$	78.21±0.02$^{b.C}$
	SMY	77.61±0.09$^{b.B}$	76.89±0.31$^{a.B}$	76.75±0.10$^{a.B}$	76.78±0.13$^{a.B}$	76.69±0.22$^{a.B}$
	SWY	73.53±0.24$^{b.A}$	71.84±0.82$^{a.A}$	71.75±0.41$^{a.A}$	71.95±0.42$^{a.A}$	72.20±0.18$^{a.A}$
a*	**WY**	-0.99±0.02$^{b.E}$	-0.96±0.03$^{b.c.E}$	-0.95±0.02$^{c.E}$	-0.97±0.01$^{b.c.E}$	-1.03±0.02$^{a.E}$
	SY	-2.01±0.05$^{a.AB}$	-2.03±0.08$^{a.B}$	-2.00±0.03$^{a.B}$	-2.01±0.06$^{a.A}$	-2.01±0.14$^{a.A}$
	SIY	-2.03±0.05$^{b.A}$	-2.23±0.20$^{a.A}$	-1.95±0.02$^{b.c.B}$	-1.86±0.06$^{c.d.B}$	-1.82±0.01$^{d.B}$
	SMY	-1.59±0.03$^{b.C}$	-1.68±0.05$^{a.C}$	-1.57±0.01$^{b.cC}$	-1.59±0.04$^{b.C}$	-1.53±0.02$^{c.C}$
	SWY	-1.36±0.02$^{b.D}$	-1.29±0.15$^{a.D}$	-1.28±0.04$^{bc.D}$	-1.25±0.20^{bcD}	-1.15±0.01$^{c.D}$
b*	**WY**	9.45±0.07$^{a.C}$	9.28±0.07$^{b.B}$	9.13±0.06$^{a.C}$	9.19±0.04$^{a.C}$	9.12±0.07$^{a.C}$
	SY	7.80±0.10$^{c.A}$	7.57±0.16$^{ab.A}$	7.36±0.09$^{a.A}$	7.64±0.15$^{bc.A}$	7.47±0.26$^{ab.A}$
	SIY	8.27±0.17$^{b.B}$	7.13±0.94$^{a.A}$	7.80±0.08$^{b.B}$	7.99±0.08$^{b.B}$	7.94±0.08$^{b.B}$
	SMY	9.72±0.03$^{c.CD}$	9.54±0.16$^{b.B}$	9.35±0.05$^{a.C}$	9.33±0.10$^{a.C}$	9.25±0.03$^{a.C}$
	SWY	12.23±0.12$^{d.E}$	11.05±0.33$^{a.C}$	11.67±0.26$^{bc.E}$	11.52±0.25$^{b.E}$	11.85±0.04$^{c.E}$

*L**: lightness; *a**: redness; *b**: yellowness; WY: whole cupuassu goat milk yogurt; SY: skimmed cupuassu goat milk yogurt; SIY: skimmed with inulin cupuassu goat milk yogurt; SMY: skimmed with maltodextrin cupuassu goat milk yogurt; SWY: skimmed with whey protein cupuassu goat milk yogurt.

Values were expressed as a mean ± standard deviation (n = 3).

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

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

Table 4. Texture parameters values of low-fat cupuassu goat milk yogurts during refrigerated storage.

Parameters	Sample	Storage time (days)				
		0	**7**	**14**	**21**	**28**
Firmness (*g*)	**WY**	33.34±0.87$^{a.AB}$	32.96±0.23$^{a.A}$	33.15±0.32$^{a.A}$	33.35±0.37$^{a.A}$	33.08±0.33$^{a.A}$
	SY	33.08±0.76$^{a.A}$	33.06±0.43$^{a.A}$	33.16±0.45$^{a.A}$	33.14±0.25$^{a.A}$	33.08±0.34$^{a.A}$
	SIY	37.79±2.03$^{b.BC}$	34.66±0.69$^{ab.B}$	34.42±0.57$^{ab.B}$	34.34±1.80$^{ab.B}$	33.50±0.45$^{a.A}$
	SMY	42.11±1.96$^{b.C}$	33.36±0.62$^{a.A}$	33.51±0.42$^{a.A}$	33.12±0.21$^{a.A}$	33.52±0.31$^{a.A}$
	SWY	35.27±2.18$^{b.AB}$	33.18±1.04$^{a.A}$	33.57±0.33$^{ab.A}$	33.24±0.25$^{a.A}$	33.10±0.48$^{a.A}$
Consistency (g.sec)	**WY**	374.22±2.62$^{a.A}$	372.88±2.71$^{a.A}$	371.02±4.45$^{a.A}$	375.72±4.24$^{a.A}$	372.25±4.05$^{a.AB}$
	SY	365.21±9.30$^{a.A}$	371.64±7.05$^{a.A}$	372.01±5.35$^{a.A}$	373.43±4.70$^{a.A}$	374.12±3.53$^{a.AB}$
	SIY	391.31±8.74$^{b.AB}$	373.91±7.33$^{a.A}$	372.17±4.98$^{a.A}$	373.67±3.41$^{a.A}$	376.67±4.49$^{a.AB}$
	SMY	407.73±14.29$^{b.B}$	375.02±9.13$^{a.A}$	372.90±6.94$^{a.A}$	374.62±2.98$^{a.A}$	380.80±3.53$^{a.C}$
	SWY	366.14±2.51$^{a.A}$	372.24±11.18$^{ab.A}$	374.42±3.57$^{ab.A}$	377.13±2.36$^{b.A}$	376.25±4.88$^{b.AB}$
Cohesiveness (g)	**WY**	-5.66±0.44$^{ab.CD}$	-5.34±0.18$^{ab.CD}$	-5.68±0.24$^{a.C}$	-5.42±0.14$^{ab.BC}$	-5.17±0.35$^{b.C}$
	SY	-5.36±0.53$^{a.D}$	-5.52±0.31$^{a.C}$	-5.36±0.36$^{a.C}$	-5.11±0.09$^{a.C}$	-5.23±0.20$^{a.BC}$
	SIY	-7.24±0.36$^{a.B}$	-6.05±0.23$^{b.B}$	-6.15±0.21$^{b.B}$	-5.76±0.27$^{b.B}$	-5.70±0.29$^{b.BA}$
	SMY	-6.98±0.23$^{a.B}$	-5.76±0.18$^{b.BC}$	-5.66±0.24$^{b.C}$	-5.40±0.18$^{b.BC}$	-5.60±0.25$^{b.BAC}$
	SWY	-6.49±0.25$^{a.BC}$	-5.03±0.16$^{c.D}$	-5.32±0.20$^{bc.C}$	-5.09±0.29$^{c.C}$	-5.50±0.21$^{b.BAC}$
Index of Viscosity (g.sec)	**WY**	-0.95±0.37$^{a.B}$	-1.01±0.18$^{a.C}$	-1.09±0.11$^{a.BC}$	-1.00±0.11$^{a.C}$	-0.96±0.18$^{a.B}$
	SY	-1.14±0.36$^{a.B}$	-1.04±0.16$^{a.C}$	-1.00±0.14$^{a.BC}$	-0.95±0.14$^{a.C}$	-1.01±0.13$^{a.B}$
	SIY	-1.91±0.34$^{b.B}$	-1.41±0.22$^{a.B}$	-1.27±0.11$^{a.B}$	-1.27±0.15$^{a.B}$	-1.08±0.06$^{a.AB}$
	SMY	-1.69±0.20$^{b.B}$	-1.19±0.19$^{a.BC}$	-0.97±0.17$^{a.BC}$	-1.02±0.13$^{a.BC}$	-1.12±0.15$^{a.AB}$
	SWY	-1.56±0.21$^{b.B}$	-0.87±0.21$^{a.C}$	-0.88±0.07$^{a.C}$	-0.92±0.21$^{a.C}$	-1.05±0.14$^{a.A}$

WY: whole cupuassu goat milk yogurt; SY: skimmed cupuassu goat milk yogurt; SIY: skimmed with inulin cupuassu goat milk yogurt; SMY: skimmed with maltodextrin cupuassu goat milk yogurt; SWY: skimmed with whey protein cupuassu goat milk yogurt.

Values were expressed as a mean ± standard deviation (n = 3).

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

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

Table 5. Rheological parameters for low-fat cupuassu goat milk yogurts during refrigerated storage.

Sample	Days	Herschel-Bulkley				Apparent viscosity (mPa s)
		R^2	**$\sigma_\circ$** (Pa)	***K*** (mPa s^n)	***n***	
WY	0	0.99^{a,A}	0.58^{c,AB}	777.30^{b,C}	1.01^{b,B}	269.95$^{b.A}$
	7	0.99^{a,A}	0.21^{b,A}	207.00^{a,B}	0.67^{a,A}	109.31$^{a.B}$
	14	0.99^{a,A}	0.21^{b,A}	201.00^{a,B}	0.66^{a,A}	99.31$^{a.B}$
	21	0.99^{a,A}	0.26^{b,A}	156.00^{a,B}	0.71^{a,A}	97.98$^{a.B}$
	28	0.99^{a,A}	0.10^{a,A}	152.00^{a,B}	0.70^{a,A}	81.98$^{a.C}$
SY	0	0.99^{a,A}	0.38^{b,A}	137.00^{a,A}	0.90^{b,B}	157.30$^{c.A}$
	7	0.99^{a,A}	0.11^{a,A}	178.00^{a,B}	0.72^{a,A}	91.98$^{b.B}$
	14	0.99^{a,A}	0.11^{a,A}	157.00^{a,B}	0.61^{a,A}	75.31$^{ba.B}$
	21	0.99^{a,A}	0.06^{a,A}	121.00^{a,B}	0.69^{a,A}	61.99$^{a.A}$
	28	0.99^{a,A}	0.02^{a,A}	127.00^{a,B}	0.63^{a,A}	53.99$^{a.B}$
SIY	0	0.99^{a,A}	1.21^{c,A}	463.00^{b,B}	1.03^{c,B}	411.91$^{b.AB}$
	7	0.99^{a,A}	0.29^{b,A}	360.00^{ab,B}	0.80^{b,A}	165.30$^{a.C}$
	14	0.99^{a,A}	0.36^{b,A}	238.00^{aB,}	0.70^{b,A}	169.29$^{a.D}$
	21	1.00^{a,A}	0.14^{a,A}	297.00^{a,B}	0.72^{b,A}	130.64$^{a.C}$
	28	0.99^{a,A}	0.08^{a,A}	220.00^{a,B}	0.53^{a,A}	129.97$^{a.E}$
SMY	0	1.00^{a,A}	0.70^{b,B}	620.00^{b,BC}	0.95^{b,B}	474.56$^{b.B}$
	7	0.99^{a,A}	0.32^{a,A}	286.00^{a,B}	0.69^{a,A}	156.64$^{a.C}$
	14	0.99^{a,A}	0.29^{a,A}	297.00^{a,B}	0.64^{a,A}	143.30$^{a.C}$
	21	0.99^{a,A}	0.17^{a,A}	284.00^{a,B}	0.64^{a,A}	129.97$^{a.C}$
	28	0.99^{a,A}	0.23^{a,A}	206.00^{a,B}	0.66^{a,A}	101.98$^{a.D}$
SWY	0	1.00^{a,A}	0.32^{b,A}	105.00^{b,A}	1.15^{a,B}	152.63$^{b.A}$
	7	0.99^{a,A}	0.14^{a,A}	32.60^{a,A}	1.12^{a,B}	59.99$^{a.A}$
	14	0.99^{a,A}	0.12^{a,A}	30.00^{a,A}	1.08^{a,B}	49.32$^{a.A}$
	21	0.99^{a,A}	0.14^{a,A}	39.10^{a,A}	0.99^{a,B}	53.32$^{a.A}$
	28	0.99^{a,A}	0.11^{a,A}	39.80^{a,A}	0.93^{a,B}	42.99$^{a.A}$

R^2: determination coefficient of model; $\sigma_{0:}$ yield stress; *K*: coefficient of consistency; *n:* flow behavior index; WY: whole cupuassu goat milk yogurt; SY: skimmed cupuassu goat milk yogurt; SIY: skimmed with inulin cupuassu goat milk yogurt; SMY: skimmed with maltodextrin cupuassu goat milk yogurt; SWY: skimmed with whey protein cupuassu goat milk yogurt.

Values were expressed as a mean ± standard deviation (n = 3).

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

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

Table 6. Mean sensory liking scores for the low-fat cupuassu goat milk yogurts.

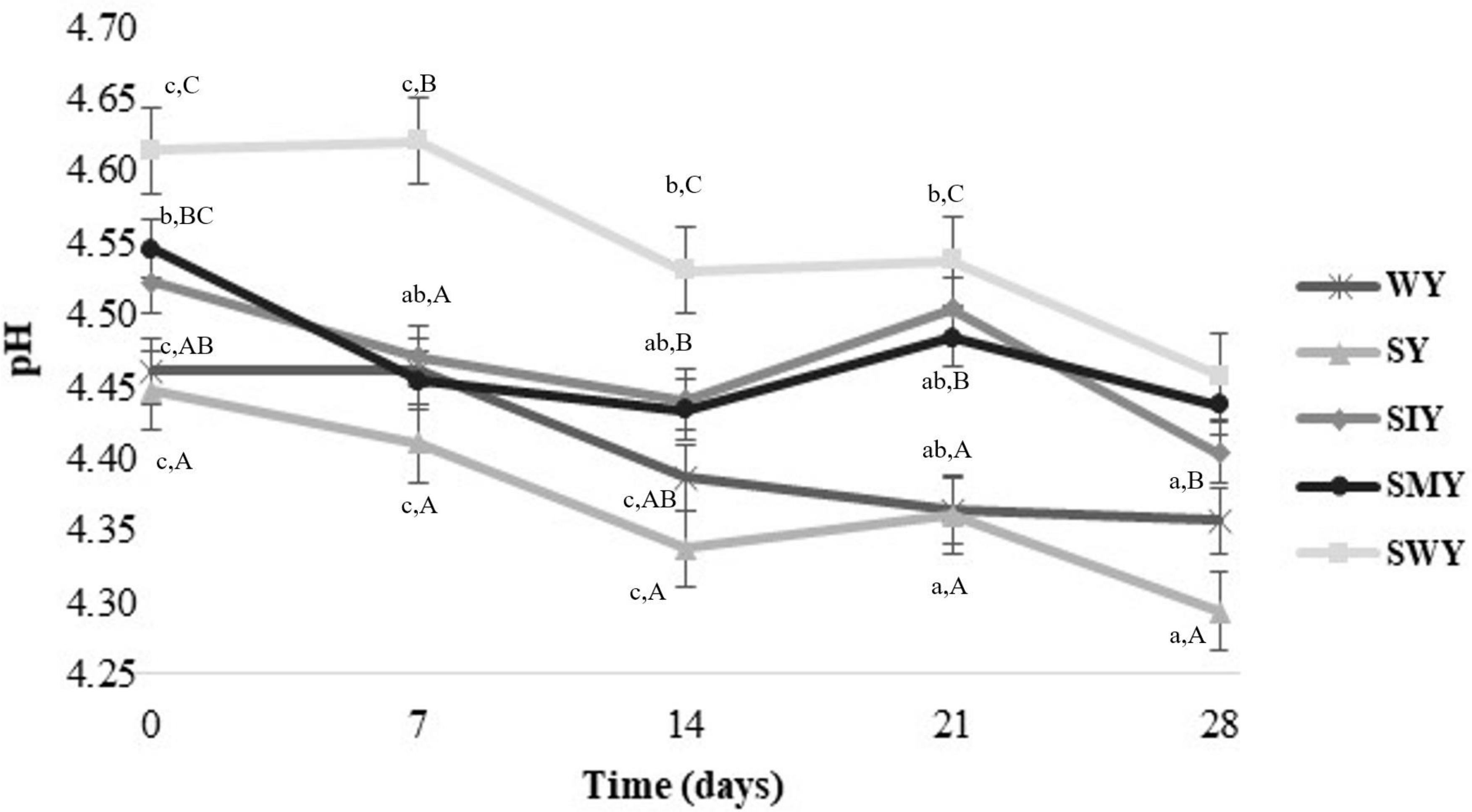
Treatment	Attribute[1]							
	Appearance	Color	Aroma	Flavor	Texture	Viscosity	Overall acceptability	Purchase intention
WY	6.65±1.96^{C}	6.90±1.78^{C}	5.80±2.24^{BC}	4.83±2.05^{B}	6.34±1.97^{C}	6.32±1.96^{C}	5.31±2.07^{B}	2.61±1.17^{B}
SY	4.97±2.02^{A}	5.31±1.95^{A}	4.24±2.17^{A}	3.04±1.87^{A}	4.18±2.01^{A}	4.24±2.02^{A}	3.50±1.89^{A}	1.62±0.88^{A}
SIY	6.00±1.86^{BC}	6.14±1.71^{B}	5.32±2.23^{B}	4.60±2.28^{B}	5.80±1.78^{BC}	5.72±1.89^{BC}	5.03±2.13^{B}	2.41±1.16^{B}
SMY	5.80±2.09^{B}	5.97±1.95^{AB}	5.30±2.29^{B}	4.54±2.11^{B}	5.44±2.03^{B}	5.48±1.91^{B}	4.81±1.99^{B}	2.24±1.10^{B}
SWY	5.83±2.00^{B}	5.93±1.98^{AB}	6.28±2.26^{C}	4.93±2.39^{B}	5.73±1.99^{BC}	5.68±1.93^{BC}	5.21±2.10^{B}	2.41±1.19^{B}

[1]Purchase intention was evaluated in a structured 5-point hedonic scale, whereas the other attributes were evaluated on a 9-point hedonic scale.

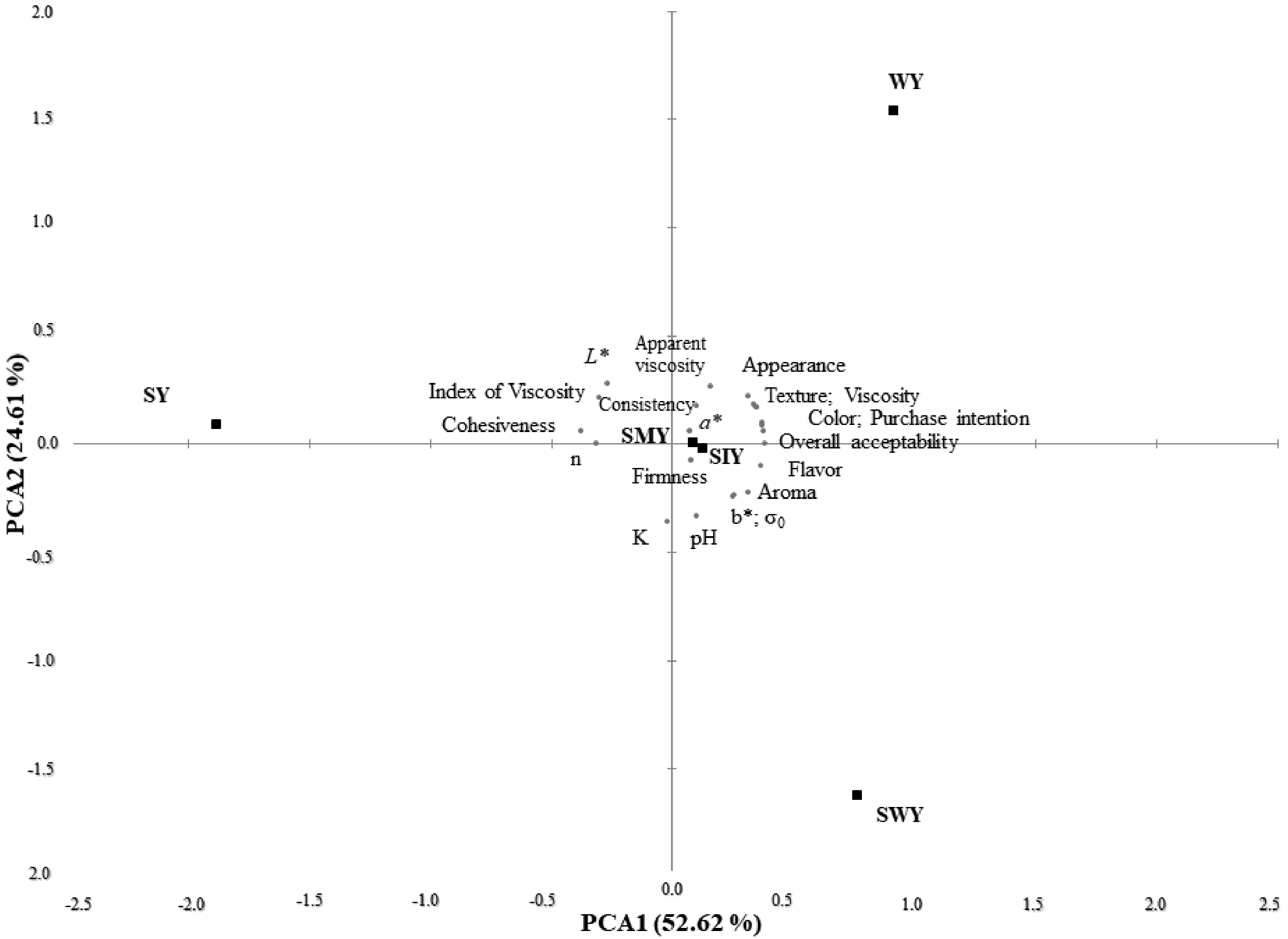
WY: whole cupuassu goat milk yogurt; SY: skimmed cupuassu goat milk yogurt; SIY: skimmed with inulin cupuassu goat milk yogurt; SMY: skimmed with maltodextrin cupuassu goat milk yogurt; SWY: skimmed with whey protein cupuassu goat milk yogurt.

Values were expressed as a mean ± SD.

$^{A.C}$ Different uppercase superscripts indicate significant differences among treatments of goat milk yogurts. $P < 0.05$.


4.70
4.65
4.60
4.55
4.50
4.45
4.40
4.35
4.30
4.25
pH
0
7
14
21
28
Time (days)
c,C
c,B
b,C
b,C
b,BC
ab,A
ab,B
ab,B
c,AB
c,A
c,A
c,AB
ab,A
a,B
c,A
a,A
a,A
WY
SY
SIY
SMY
SWY

677



2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
2.0
-2.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
2.5
PCA2 (24.61 %)
PCA1 (52.62 %)
WY
SY
SWY
SMY
SIY
L*
Apparent viscosity
Appearance
Index of Viscosity
Consistency
Texture; Viscosity
Color; Purchase intention
Cohesiveness
a*
Overall acceptability
n
Flavor
Firmness
Aroma
b*; σ0
K
pH