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Pilosocereus gounellei (xique-xique) jam is source of fibers and mineral and improves the nutritional value and the technological properties of goat milk yogurt

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ABSTRACT

This study aimed to evaluate the impact of xique-xique jam addition on the nutritional value and physicochemical and sensory characteristics of goat milk yogurt. The jam was characterized for its physicochemical characteristics, mineral profile, antinutritional factors, and phenolic compounds (profile and bioaccessibility). The jam presented a dark yellow color, was slightly acid (pH 4.61), and was characterized by its carbohydrate (67.17 g/100 g) and fiber (2.60 g/100 g) contents, mainly in an insoluble form (1.71 g/100 g). Potassium, magnesium, calcium, and manganese were found as main minerals, and there was no significant concentration of the antinutritional compounds (tannins, trypsin inhibitor and phytic acid). Finally, 13 phenolic compounds were identified from the flavanols, flavonols, phenolic acids and flavanones groups, presenting 2.79–172.52% bioaccessibility. The jam addition resulted in yogurts with higher nutritional value (lipid, protein and mineral content), and technological properties (higher moisture content during storage, lower acidity, and reduced viscosity) than conventional yogurt, with no impact on sensory acceptance (appearance, color, consistency, aroma, flavor, and overall acceptance) or sensory characteristics (Just about Right, aroma, consistency, texture, sweetness, flavor and acidity). It can be concluded that xique-xique jam can improve the nutritional value and technological properties of goat milk yogurt.

1. Introduction

The global goat milk market size was valued at $8.5 billion in 2018, and is expected to reach $11.4 billion by 2026, growing at a compound annual rate of 3.8% from 2019 to 2026 (Kadam, Sangwai, & Deshmukh, 2019). Yogurt is a fermented dairy product widely consumed due to its nutritional value and health benefits (Pan, Liu, Lou & Lou, 2019). Goat milk can be suitable for the yogurt production, mainly because of its higher nutritional value compared to cow milk, as well as, to the health benefits associated with its consumption (Santis, Giacinti, Chemello, & Frangipane, 2019). Goat milk yogurt, however, is less acceptable than yogurt made with cow milk, because goat milk has a different flavor due to the presence of the capric, caprylic and caproic acids in its composition (Costa et al., 2017). It is characterized by a weak curd and a low viscosity, due to the low levels of α_{S1} casein (Costa et al., 2017).

Improvements in the quality and sensory characteristics of goat milk

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yogurt have been attempted, such as the addition of cultures with flavor-enhancement characteristics (Santis et al., 2019), addition of fruit or fruit pulps (Cușmenco & Bulgaru, 2020; Feng et al., 2019), and the use of gums (Park et al., 2019). The addition of fruits and vegetables can contribute to increase the nutritional value and mask the goat flavor, promoting the consumption of goat milk dairy products (Feng et al., 2019). Furthermore, they can act as stabilizing agents in yogurts, due to their desirable functional attributes (Wang, Kristo, & LaPoite, 2020).

One of the potential additives is xique-xique (*Pilosocereus gounellei*), a cactacea widely spread across and adapted to the dry climate of the Northeast region of Brazil (Furtado et al., 2019). In vivo studies have demonstrated the protective and anti-inflammatory effects of xique-xique on edema in paw (Dias et al., 2015), and rats with induced colitis (Assis et al., 2019), as well as its gastroprotective effects (Sousa et al., 2018). Therefore, exploration of the constituents of xique-xique and its potential for use in the development of new products needs to be explored (Dias et al., 2015).

The cladodes of xique-xique have a limited shelf-life. Their use as additions to the processing of food products would prolong this time and contribute to the emergence of an economically viable market for this cactacea (Toit, Wit, Osthoff, & Hugo, 2018). Their application in the processing of jams could increase the consumer acceptance, shelf life, and preservation of the bioactive compounds in the food (Shinwari & Rao, 2018). The use of xique-xique in food products is still scarce; some examples are xique-xique juice (Assis et al., 2019; Ribeiro et al., 2020), fresh pasta enriched with xique-xique flour (Oliveira & de Oliveira, 2019), and cereal bars with xique-xique flour (Araújo, dos Reis, & de Oliveira, 2019). To our knowledge, however, there have been no studies that used xique-xique in the processing of jam and/or dairy products.

Considering the processing of goat milk yogurts with improved quality as well as the absence of studies with xique-xique, this study aimed to i) characterize the xique-xique jam regarding its physicochemical characteristics, mineral profile, antinutritional factors, and phenolic compounds (profile and bioaccessibility) and, ii) evaluate the impact of the addition of xique-xique jam on the nutritional value, and physicochemical and sensory characteristics of goat milk yogurt.

2. Material and methods

2.1. Xique-xique cladodes

Xique-xique cladodes (3 lots of 30 kg, April 2016) were obtained from a private cultivation area located in the municipality of Boa Vista, in the state of Paraíba, Brazil (latitude 7.16762352, longitude −36.1432815). The plant was identified by the Agricultural Sciences Center of the Federal University of Paraíba (CCA/UFPB) and the certified specie (number 17562) was deposited at the Herbário Prof°. Jaime Coelho Morais (CCA/UFPB). The collection was authorized by the Brazilian Biodiversity Information System (number 62681) and the National System for the Management of Genetic Heritage (SISGEN, number AA17429).

The cladodes were selected considering their physical integrity; and the spines were removed at the time of collection. Then, they were transported in polystyrene boxes, under refrigeration at a temperature of 5 °C ± 1.0. After adequate hygiene and disinfection by immersion in chlorinated water (100 ppm) for 15 min, the cladode (vascular cylinder) had the shells removed with the aid of a knife and was cut into pieces of 5 cm × 5 cm. These were then processed in a horizontal pulper (MecVal®) until the pulp was obtained, stored in glass bottles, and used in the preparation of the jam.

2.2. Jam and yogurt processing

In the preparation of the jam, a proportion of 70:30% pulp:sugar (w/w) was used. The mixture was cooked for 45 min, with manual stirring until it reached 62–65 °Brix, which was measured using a digital refractometer (Hanna® brand, model HI 96801). Then, the jam was transferred, still hot, to a previously sterilized glass container and stored at room temperature 27 ± 2 °C until analysis (day 1 of storage) or used in the yogurt processing.

The yogurts were processed based on the methodology described by Silva et al. (2017). Two formulations were prepared: (CY) conventional treatment (with sucrose), and (XY) with xique-xique jam. Pasteurized goat milk was subjected to heat treatment (90 °C/10 min) and cooled to 45 °C. Then, 5 g/100 g sucrose was added to the CY treatment. The starter cultures (*Streptococcus thermophillus* and *Lactobacillus delbrueckii* subsp. *bulgaricus*, Christian Hansen®, Valinhos, Brasil, 10^8 cfu/mL) were inoculated in concentrations of 0.4 g/L and fermentation was carried at 45 °C for 4 h. Then, the yogurt samples were cooled to 5 °C, the clot broken by a glass rod, and the jam added in concentrations of 10 g/100 g to the XY. Finally, the products were placed in high density polyethylene bottles and stored under refrigeration (5 °C) for 28 days. The yogurts were evaluated on days 1, 14 and 28 of storage, except for sensory analysis and mineral profile, which were conducted on day 14 of storage.

2.3. Physical-chemical characterization of the jams and yogurts

The jam was evaluated for physical parameters of water activity (Aw) (AquaLab model CX-2), pH (Quimis model Q400as), titratable acidity (TA), total soluble solids (TSS; digital refractometer, Hanna®, HI 96801) and color (Konica Minolta colorimeter, model CR 400). The moisture, ash, fiber (total, soluble, and insoluble), and protein contents were determined according to the methodology recommended by the Association of Official Analytical Chemists (AOAC, 2016), and lipids according to Folch, Lees & Stoane-Stanley (1957). Carbohydrates were estimated by difference. The total energy was calculated using the conversion factors: 4 kcal/g for carbohydrates, 4 kcal/g for proteins, and 9 kcal/g for lipids.

The yogurt was evaluated for pH (Quimis model Q400as), color (Konica Minolta colorimeter, model CR 400), TA, moisture, ash, lipids, protein, and lactose contents (AOAC, 2016). Viscosity was evaluated using a Brookfield viscometer model DV II + Pro coupled with a thermostatic bath to control the temperature of the samples. The analyses were carried out at a rotation speed of 40–200 rpm and a temperature of 5 ± 1 °C, measured with a Brookfield Thermosel Spindle (SC4-27).

2.4. Mineral profile of the jams and yogurts

For the mineral profile, microwave-assisted acid digestion was performed, at a maximum temperature of 170 °C for 37 min followed by reverse osmosis (Gehaka®, São Paulo, Brazil) (AOAC, 2016). Minerals were determined in an inductive coupling plasma atomic emission spectrometer (ICP OES 5100 VDV, Agilent Technologies, Tokyo, Japan) using the following wavelengths: Ca (317.933 nm), Cu (324.754 nm), Fe (259.940 nm), Mg (279.553 nm), Mn (257.610 nm), P (213.618 nm), Na (589.592 nm), Se (196.026 nm), K (766.491 nm), and Zn (206.200 nm). The analytical curves for minerals were prepared from dilutions of 10 mg/100 mL analytical standards (Specsol - Quimlab, Jacareí, Brazil) and 1000 mg/100 mL (Titrisol - Merck, Darmstadt, Germany) in the ranges of 0.041–41.0 mg/100 mL for Ca and Na, 0.062–62.0 mg/100 mL for P, 0.00025 a 0.05 mg/100 mL for Se, 0.015–14.5 mg/100 mL for Mg, 0.061–61.0 mg/100 mL for K, and 0.001–1.0 mg/100 mL for Cu, Fe, Mn and Zn, with correlation coefficients (R^2) greater than 0.9999.

2.5. Antinutritional factors, phenolic profile and bioaccessibility and antioxidant activity of the jams

Total tannins (AOAC, 2016), phytic acid content (Latta & Eskin, 1980), and trypsin inhibitor (Rackis, McGhee, Liener, Kakade, & Puski, 1974) were evaluated as antinutritional factors.

The identification of the phenolic compounds was carried out according to Padilha et al. (2018), with adaptations to the gradient and runtime for quantification of stylbenes, flavonols and flavanones. The analysis was performed using an Agilent 1260 Infinity LC System liquid chromatograph (Agilent Technologies, Santa Clara - USA) coupled to a diode arrangement detector (DAD) (model G1315D). The column used was Zorbax Eclipse Plus RP-C18 (100 × 4.6 mm, 3.5 μm) and the Zorbax C18 pre-column (12.6 × 4.6 mm, 5 μm) (Zorbax, USA). The data were processed using the OpenLAB CDS ChemStation Edition software (Agilent Technologies, Santa Clara - USA) and the identification and quantification was done by comparison with standard external standards.

The antioxidant activity measured by the ability to deactivate the 2,2′-diphenyl-2-picryl-hydrazil (DPPH■) radical and the antioxidant potential by the FRAP method were determined following procedures described by Toit et al. (2018) and Dutra et al. (2017). Standard curves were performed with Trolox and the results expressed in μM Trolox/100 g of jam.

For the bioaccessibility assessment, the samples were digested in three sequential phases: oral, gastric, and intestinal, as described by Dutra et al. (2017) using a cellulose dialysis membrane (molecular weight cut of 12000 Da) filled with 15 mL of $NaHCO_3$ (0.5 mol/L) to simulate the intestinal barrier. The in (dialyzed) and out (non-dialyzed) phases were collected. Bioaccessibility was expressed as a percentage and was determined as follows Equation: Bioaccessibility (%) = (BC dialyzed/BC non-digested) X 100.where BC dialyzed corresponds to the free phenolic compound concentration in the dialyzed portion and BC non-digested is the free phenolic compound concentration in the FP.

2.6. Sensory analysis of the yogurts

The acceptance test was conducted with 102 consumers of goat milk products (22 men and 80 women, with ages in the range of 19–30 years old, with a mean age of 24 years), which evaluated the appearance, color, consistency, aroma, flavor, and overall acceptance of the products using a structured hedonic scale of nine points (1 = very disliked; 5 = neither liked/disliked; 9 = liked very much). The purchase intention was evaluated using a 5-point scale (1 = would never buy; 3 = maybe buy/maybe not buy; 5 = would certainly buy). The consumers also assessed how close the samples were to the ideal, evaluated by the JAR (Just About Right) scale (1 = extremely less than ideal; 5 = extremely greater than ideal) for the attributes of color, aroma, consistency, texture, sweetness, flavor and acidity, according to the methodology described by Costa et al. (2017). In all tests, the samples were served simultaneously and randomly, at approximately 5 °C, in white plastic cups of 50 mL coded with random numbers of 3 digits.

2.7. Statistical analysis

All experiments were performed three times in triplicate. The results were submitted to the t-Student test (between formulations), and ANOVA followed by Tukey test (storage times) considering $p < 0.05$. Penalty analysis was performed on JAR attributes and overall liking data for each goat milk yogurt. Penalty analysis plots were used to show penalties (mean drops in overall liking) for each non-JAR attribute for each of the yogurts. The non-JAR attributes having significant penalties ($p < 0.05$) are highlighted with a "*" in the penalty analysis plots (Nguyen & Wismer, 2019; Fig. S1). The attributes in the upper right-hand corner of penalty analysis plots had the highest skews and were associated with the greatest penalties. Only significant non-JAR categories with a substantial proportion of participants (>20%) were considered for interpretation of results (Sánchez-Rodríguez, Cano-Lamadrid, Carbonell-Barrachina, Sendra, & Hernández, 2019). Analyses were done using the GraphPad Prism 5.0 software (GraphPad Software Inc., San Diego, CA, USA).

3. Results and discussion

3.1. Characterization of the xique-xique jams

Table 1 presents the chemical composition and physicochemical characteristics of the xique-xique jams. The jams presented 29.02 g/100 g of moisture, 0.28 g/100 g of protein, 0.83 g/100 g of ash, 2.60 g/100 g of total fiber (1.71 of insoluble and 0.89 of soluble fiber), 67.17 g/100 g of carbohydrates, and 269.8 kcal/100 g. Therefore, the xique-xique jam was characterized as source of fibers mainly in insoluble form. Dietary consumption of fibers is associated to the reduction of the risk of cardiovascular and digestive tract diseases, as fibers can lower the glycemic index and cholesterol levels (Tosh & Bordenave, 2020).

The xique-xique jam presented a dark yellow color (L*38.70, a* −0.30, and b* 13.15), associated to the raw material (green color) and the processing (caramelization during cooking), resulting in the production of brown/yellow pigments. The jam had pH of 4.61, TSS of 63.08 °Brix, Aw of 0.85, and TA of 0.14%, with the pH and the TA suggesting its use in products with a slightly acid characteristic.

Table 2 presents the mineral profile of the xique-xique jam. The jams presented 657 mg/100 g of potassium, 535 mg/100 g of magnesium, 149 mg/100 g of calcium, 50 mg/100 g of manganese, 44.10 mg/100 g of sodium, 5.70 mg/100 g of phosphorous, 2.86 mg/100 g of iron, 1.07 mg/100 g of zinc, and 0.019 mg/100 g of selenium. Therefore, the xique-xique jam was characterized by the presence of higher concentrations of potassium, magnesium, calcium, and manganese. Potassium is the main intracellular cation and helps in the normal functioning of the cells, while magnesium is associated with bone health, and maintenance of the levels of calcium and potassium (National Academies of Sciences, Engineering, and Medicine, 2019). Calcium is associated to the structure of bones and teeth, it composes the blood plasma, helps the development and contraction of the muscles, and regulates blood pressure and heart beat (Matera et al., 2018). Manganese participates in the formation of the bones, and in reactions involving cholesterol, carbohydrate, and amino acid metabolism (National Academies of Sciences, Engineering, and Medicine, 2019).

The concentrations of some minerals were higher than those found in fresh samples of xique-xique cladodes, such as potassium (mg/100 g) (308.4), magnesium (182.40), and manganese (7.71) (Bezerril, 2017). Therefore, the processing of the jams resulted in higher concentrations of the minerals, which is interesting from the nutritional point of view. One portion of jam (20 g) would provide 6.91% of the recommended daily intake of selenium, 7.15% iron, 25.48% magnesium, and 434.78% of manganese. For the other minerals, the recommended daily intake

Table 1
Chemical composition and physicochemical characteristic of xique-xique jam.

Variable	
Water activity	0.85 ± 0.000
Titratable acidity (%)	0.14 ± 0.01
pH	4.61 ± 0.08
Total soluble solids (°Brix)	63.08 ± 0.49
L*	38.70 ± 8.70
a*	−0.30 ± 0.34
b*	13.15 ± 4.91
Moisture (g/100 g)	29.02 ± 2.67
Protein (g/100 g)	0.28 ± 0.05
Lipids (g/100 g)	NI*
Ash (g/100 g)	0.83 ± 0.04
Total fiber (g/100 g)	2.60 ± 0.01
Insoluble fiber (g/100 g)	1.71 ± 0.01
Soluble fiber (g/100 g)	0.89 ± 0.01
Carbohydrates (g/100 g)	67.17 ± 0.00
Caloric value (Kcal/100 g)	269.8 ± 0.00

NI – Not identified. L varying from 0 (black) to 100 (white), a* varying from red (+a*) to green (-a*), and b* varying from yellow (+b*) to blue (-b*).

Table 2
Mineral profile of the xique-xique jam.

Variables	Mineral composition (mg/100 g)	% Recommended daily intake (20 g portion)	Recomendation (mg)[a]
Potassium	657.00 ± 17.00	3.86	3.400[b]
Magnesium	535.00 ± 14.00	25.48	420[c]
Calcium	149.00 ± 3.00	2.98	1000[b]
Manganese	50.00 ± 2.00	434.78	2.3[b]
Sodium	44.10 ± 0.30	0.59	1500[b]
Phosphorous	5.70 ± 0.10	0.16	700[c]
Iron	2.86 ± 0.06	7.15	8[c]
Zinc	1.07 ± 0.02	1.95	11[c]
Selenium	0.019 ± 0.004	6.91	0.055[c]

[a] Based on National Academies of Sciences, Engineering, and Medicine 2019. Dietary Reference Intakes, 2019. Washington, DC: The National Academies Press. Based on an adult man aged 31–50 years.
[b] Adequate Intake.
[c] Recommended Dietary Allowances.

would be from 0.16 to 3.86%. As the jam contains a relevant concentration of minerals, especially manganese, it could be a commercial option to serve groups of individuals that lack these minerals. Deficiency of manganese is associated with impairment in growth and skeletal development, alterations in the reproductive function and glucose tolerance, and changes in lipid and carbohydrate metabolism (Erikson & Aschner, 2019). At the same time, selenium deficiency is associated with a higher predisposition to illness related to other stresses, such as Keshan disease (cardiomyopathy) and Kashin-Beck disease (cartilage disease). Anemia is the main nutritional deficiency associated with iron, but other symptoms can also be observed, such as decreases in the physical work capacity, and impairment in the cognitive function (National Academies of Sciences, Engineering, and Medicine, 2019). Magnesium deficiency is related to hypocalcemia, muscle cramps, and spontaneous carpal-pedal spasm, among others (National Academies of Sciences, Engineering, and Medicine, 2019).

3.2. *Antinutritional compounds, phenolic compound, profile, antioxidant activity and bioaccessibility of the jams*

Xique-xique is a raw material that has not been extensively investigated or commercialized, providing a reason for the investigation of the presence of some antinutrients such as tannins, trypsin inhibitor and phytic acid. In the present study, it was possible to detect levels of 34.44 mg/100 g of tannins in the jam. Tannins can have beneficial characteristics because they are defined as phenolic compounds, belonging to the non-flavonoid class (Shinwari & Rao, 2018). On the other hand, condensable tannins are responsible for astringency in fruits and may have anti-nutritional characteristics because they precipitate proteins, carbohydrates, and minerals (Li, Huang, Luo, & Tamer, 2020). The jams presented lower than 0.10 mg/100 g of trypsin inhibitor, and lower than 0.05 mg/100 g of phytic acid. These low concentrations may be associated with the cooking process: trypsin inhibitors are denatured through heat treatment, and phytic acid undergoes dephosphorylation (Li et al., 2020). Thus, the use of xique-xique in jams could guarantee a nutritional quality to the product, with no significant concentrations of the antinutritional compounds.

Table 3 presents the phenolic compounds profile and bioaccessibility of the xique-xique jam. The xique-xique jams presented 13 phenolic compounds, which belong to the groups of flavanols, flavonols, phenolic acids, and flavanones. The flavonoids (e.g., flavanones, flavones, flavonols, anthocyans, and flavanols) are a subcategory of polyphenols and may exert a wide range of positive health benefits, such as reduction in the incidence of cardiovascular diseases, osteoporosis, diabetes, cancer, and neurodiseases (Marković et al., 2017). Furthermore, they can have anti-biofilm activity (Pejin et al., 2015). Epigallocatechin gallate was the main phenolic compound present (21.59 mg/g), followed by catechin (6.41 mg/g). Bioactive compounds are sensitive to heat, and thermal processing negatively affects the total phenolic content. During heat, a breakdown of the cellular structure can occur, and the raw material becomes vulnerable to non-enzymatic oxidation (Shinwari & Rao, 2018). Therefore, the phenolic compounds were maintained in the jam in suitable concentrations even after the cooking. This may be related to the high fiber content in the jam, which protected the phenolic compounds (Dutra et al., 2017).

Epicatechin, syringic acid, rutin, caffeic acid, epigallocatechin gallate, procyanidin B_2, procyanidin B1, gallic acid and catechin showed bioaccessibility ranging from 2.79 to 172.52%. The highest accessibility was observed for catechin (172.52%), gallic acid (130.54%), procyanidin B1 (110.37%), procyanidin B2 (32.01%), epigallocatechin gallate (28.16%) and caffeic acid (26.56%). The high bioaccessibility of catechin is related to the partial hydrolysis of proanthocyanidins when in contact with the intestinal pH. Furthermore, some phenolic acids present a chemical rearrangement, which increase the bioaccessibility (Dutra et al., 2017).

The xique-xique jam presented antioxidant activity of 63.43 μM TEAC/100 g for DPPH and 121.60 μM TEAC/100 g for FRAP. The

Table 3
Phenolic compounds profile and bioaccessibility of the xique-xique jam.

Phenolic compound	Concentration (mg/g)	IN (after dialysis)	OUT (no dialysis)	Bioaccessibility %
Flavanols				
Catechin	6.41 ± 0.12	11.06 ± 0.21	153.77 ± 0.45	172.52
Epicatechin	0.26 ± 0.01	0.01 ± 0.00	1.09 ± 0.02	2.79
Epigallocatechin galato	21.59 ± 0.22	6.08 ± 0.12	64.78 ± 0.42	28.16
Procianidin B1	0.26 ± 0.01	0.29 ± 0.01	1.86 ± 0.03	110.37
Procianidin B2	0.78 ± 0.01	0.25 ± 0.01	3.53 ± 0.04	32.01
Flavonols				
Quercetin 3-glycoside	0.40 ± 0.01	0.00 ± 0.00	1.65 ± 0.02	0.00
Rutin	0.43 ± 0.01	0.06 ± 0.01	1.12 ± 0.02	13.97
Kaempferol glycoside	0.21 ± 0.01	0.00 ± 0.00	0.78 ± 0.01	0.00
Phenolic acids				
Galic	0.96 ± 0.01	1.25 ± 0.03	31.33 ± 0.12	130.54
Caffeic	0.31 ± 0.01	0.08 ± 0.01	1.23 ± 0.03	26.58
Syringic	0.68 ± 0.01	0.06 ± 0.01	2.38 ± 0.04	9.21
Chlorogenic	0.37 ± 0.01	0.00 ± 0.00	1.31 ± 0.03	0.00
Flavanones				
Hesperidin	2.44 ± 0.04	0.00 ± 0.00	7.29 ± 0.05	0.00

antioxidant activity obtained by FRAP was higher than that of DPPH, which may have been influenced by the iron content of sugar present in the composition of the jam. Furthermore, DPPH radicals do not react with flavonoids without a hydroxyl group in ring B or with aromatic acids with only one hydroxyl group (Vukoja, Pichler, & Kopjar, 2019).

3.3. Physicochemical characteristics of the yogurts

Table 4 presents the chemical composition and physicochemical characteristics of the yogurts. The yogurts presented 82.30–84.02 g/100 g of moisture, 3.24–3.98 g/100 g of protein, 0.63–0.80 g/100 g of ash, 2.20–3.00 g/100 g of lipid, and 3.40–4.40 g/100 g of lactose. The yogurts had 4.18–4.42 pH, 0.74–0.90% lactic acid of titratable acidity, and slightly yellow color (L* = 65.72 to 72.73, a* = −1.74 to −1.95, b* = 3.22–4.54).

The addition of the xique-xique jam to the yogurts resulted in a decrease in the moisture content ($p < 0.05$), with a consequent increase in the lipid and protein contents ($p < 0.05$, day 1). At the same time, a decreased lactose content was observed ($p < 0.05$). This result is related to the high total soluble solids of the jam (Table 1), which decreases the moisture content. Furthermore, a concentration of the other components is commonly observed when moisture content is reduced. The lower lactose content suggests that the development of the starter culture was improved in this yogurt, resulting in a higher consumption of lactose. This result can be associated with the addition of the jam only after the fermentative process, while in the CY, the sucrose was added before fermentation. Sucrose can inhibit the development of lactic acid bacteria (Santos et al., 2019). Therefore, the yogurt with xique-xique jam had a higher nutritional value than conventional yogurt.

Table 4
Chemical composition and physicochemical characteristic of the yogurts.

Parameter	Storage	Treatment	
	Days	CY	XY
Moisture (g/100 g)	1	83.46 ± 0.01^{Aa}	82.30 ± 0.01^{Cb}
	14	82.48 ± 0.02^{Cb}	84.02 ± 0.09^{Aa}
	28	82.95 ± 0.07^{Ba}	83.19 ± 0.10^{Ba}
Ash (g/100 g)	1	0.77 ± 0.03^{Aa}	0.78 ± 0.01^{Aa}
	14	0.70 ± 0.06^{Aa}	0.80 ± 0.03^{Aa}
	28	0.65 ± 0.01^{Aa}	0.63 ± 0.01^{Ba}
Protein (g/100 g)	1	3.50 ± 0.01^{Bb}	3.98 ± 0.01^{Aa}
	14	3.49 ± 0.02^{Ba}	3.24 ± 0.11^{Ba}
	28	3.66 ± 0.01^{Aa}	3.32 ± 0.01^{Bb}
Lipids (g/100 g)	1	2.50 ± 0.01^{Ab}	3.00 ± 0.01^{Aa}
	14	2.65 ± 0.14^{Aa}	2.85 ± 0.35^{Aa}
	28	2.20 ± 0.28^{Aa}	3.00 ± 0.01^{Aa}
Lactose (g/100 g)	1	3.83 ± 0.14^{Ba}	3.54 ± 0.07^{Bb}
	14	4.29 ± 0.02^{Aa}	3.40 ± 0.01^{Cb}
	28	4.40 ± 0.02^{Aa}	4.22 ± 0.01^{Ab}
pH	1	4.25 ± 0.01^{Ba}	4.28 ± 0.01^{Ba}
	14	4.18 ± 0.01^{Ca}	4.19 ± 0.01^{Ca}
	28	4.38 ± 0.01^{Aa}	4.42 ± 0.01^{Aa}
Titratable acidity (%)	1	0.88 ± 0.01^{Aa}	0.80 ± 0.01^{Ab}
	14	0.85 ± 0.01^{Aa}	0.74 ± 0.01^{Ab}
	28	0.90 ± 0.03^{Aa}	0.76 ± 0.03^{Ab}
L*	1	71.82 ± 0.57^{Aa}	65.72 ± 0.49^{Bb}
	14	72.73 ± 1.12^{Aa}	69.11 ± 0.55^{Aa}
	28	68.55 ± 0.33^{Ba}	69.63 ± 0.64^{Aa}
a*	1	−1.84 ± 0.02^{ABa}	−1.82 ± 0.01^{Ba}
	14	−1.95 ± 0.03^{Aa}	−1.92 ± 0.03^{Aa}
	28	−1.74 ± 0.04^{Ba}	−1.82 ± 0.03^{Ba}
b*	1	3.33 ± 0.04^{ABb}	4.20 ± 0.01^{Ba}
	14	3.49 ± 0.07^{Aa}	4.54 ± 0.04^{Aa}
	28	3.22 ± 0.04^{Bb}	4.42 ± 0.11^{ABa}

$^{a-b}$Mean ± standard deviation with different lowercase letters on the same line differed by the Student's *t*-test ($p < 0.05$) between treatments. $^{A-C}$Mean ± standard deviation with different capital letters in the same column differed by Tukey's test ($p < 0.05$) over storage time. Formulations: CY (control yogurt), and XY (yogurt added with xique-xique jam). L* varying from 0 (black) to 100 (white), a* varying from red (+a*) to green (-a*), and b* varying from yellow (+b*) to blue (-b*).

During storage, there was a reduction in moisture content of the CY (comparing the 1st with the 28th storage days), with a consequent increase in the protein and lactose contents ($p < 0.05$). On the other hand, the yogurt with xique-xique jam (XY) presented an increase in the moisture content during storage, with a consequent decrease in the ash and protein contents ($p < 0.05$). These results may be associated to the high water absorption capacity of the fibers presented in the xique-xique, which reduced the serum expulsion from the gel, and resulted in a higher moisture content. The higher maintenance of serum in the products could also explain the increase in the lactose content during storage in XY ($p < 0.05$). Higher moisture content is good for obtaining products with a softer texture, which is expected from goat milk yogurts.

The addition of the xique-xique jam did not alter the pH values of the products ($p > 0.05$), but it decreased the titratable acidity ($p < 0.05$). The lower acidity in the product added with xique-xique jam may be associated with the higher moisture content of the XY (Table 4), promoting a dilution of the organic acids presented in the medium. Furthermore, it can be related to the titratable acidity of the xique-xique (Table 1), which was lower than the observed in yogurt at the end of the fermentation process. The lower acidity is interesting from a consumer point of view, as consumers prefer yogurts with low acidity (Costa et al., 2017).

During storage, both yogurts (CY and XY) presented a similar behavior, with maintenance of the titratable acidity ($p > 0.05$), and oscillation of the pH values (decrease up to the 14th day and increase up to the 28th day) ($p < 0.05$). The reduced pH during the first days of storage is associated to post-acidification, as the starter cultures may produce low concentrations of lactic acid. The increased pH in the final days of storage can be associated to proteolysis of the products, with formation of basic compounds (Silva et al., 2017).

The addition of the xique-xique jam changed the color of the yogurts, resulting in products with a darker yellow color (lower L* values and higher b* values) ($p < 0.05$). The changes are associated to the dark yellow color of the jam (Table 1). During storage, there was oscillation of the a* and b* parameters, but similar values were observed on both the 1st and 28th days of storage for both formulations ($p \geq 0.05$). Considering the L* parameter, there was a reduction in the CY and an increase in the XY ($p < 0.05$). Therefore, the xique-xique jam addition resulted in a lighter colored product during storage, which is interesting from the consumer point of view.

Fig. 1 presents the apparent viscosity of the yogurt formulations. The addition of the xique-xique jam resulted in a decrease in the apparent viscosity of the products ($p < 0.05$). During storage, the apparent viscosity decreased up to the 14th day of storage and increased between this and the 28th day of storage for the CY ($p < 0.05$), while a progressive decrease was observed in the XY ($p < 0.05$). The addition of the

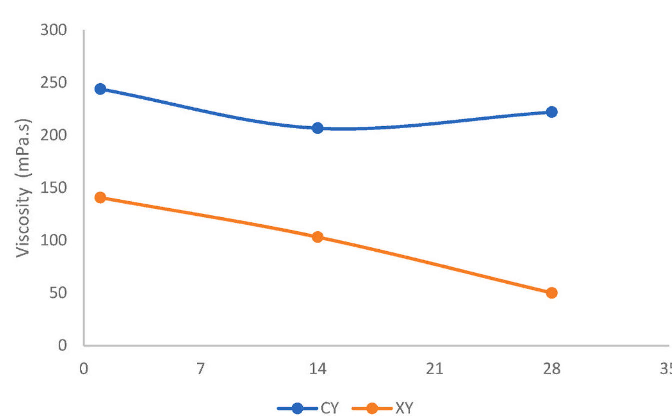

Fig. 1. Apparent viscosity of the yogurt during storage. Formulations: CY (control yogurt), and XY (yogurt added with xique-xique jam).

xique-xique jam after the fermentation process probably contributed to an initial lower viscosity of the products. The highest moisture content during storage resulted in the progressive viscosity decrease. Goat milk yogurts are characterized by low viscosity, because of the low concentrations of αs_1 casein (Costa et al., 2017). Evaluation of the impact of altered viscosity on the sensory acceptance of the products remains to be studied. .

3.4. Mineral profile of the yogurts

Table 5 presents the mineral profile of the yogurts. The yogurts presented potassium (1153–1394 mg/100 g), calcium (672.1–721.5 mg/100 g), phosphorous (507.8–543.3 mg/100 g), and sodium (209.8–214.5 mg/100 g) as the main minerals. Sodium is needed to maintain the extracellular fluid volume and plasma osmolality, while phosphorous is involved in metabolic processes and helps to maintain normal pH in the body (National Academies of Sciences, Engineering, and Medicine, 2019). One portion of yogurt (100 g) would provide 33.91–41.00% of the recommended daily intake of potassium, 67.21–72.15% of calcium, 15.23–69.43% of magnesium, 13.99–14.30% of sodium, 15.27–15.45% of zinc, and 2.61–567.39% of manganese. For the other minerals, the recommended intake would be between 0.004 and 5.13%.

The addition of the xique-xique jam increased the concentrations of calcium, iron, copper, potassium, magnesium, and manganese ($p < 0.05$). On the other hand, it reduced the phosphorous ($p < 0.05$), and maintained the sodium ($p > 0.05$). The increase in the mineral content of the yogurts corroborates the results of the mineral profile of the xique-xique jam (Table 2). Therefore, this makes it possible to increase the RDI of the minerals by 4.94% for calcium, 2.88% for iron, 7.09% for potassium, 54.20% for magnesium, and 564.78% for manganese with the addition of xique-xique jam to yogurts.

Table 5
Mineral profile of the yogurts.

Minerals (mg/100 g)	Treatments		% Recommended daily intake (100 g portion)		Recomendation (mg)[a]
	CY	XY	CY	XY	
Calcium	672.1 ± 4.15[b]	721.5 ± 9.88[a]	67.21	72.15	1000[b]
Cupper	0.04 ± 0.01[b]	0.06 ± 0.01[a]	0.004	0.006	900[c]
Iron	0.18 ± 0.01[b]	0.41 ± 0.01[a]	2.25	5.13	8[c]
Potassium	1153.00 ± 9.77[b]	1394.00 ± 7.48[a]	33.91	41.00	3.400[b]
Magnesium	63.98 ± 0.45[b]	291.6 ± 3.73[a]	15.23	69.43	420[c]
Manganese	0.06 ± 0.01[b]	13.05 ± 0.21[a]	2.61	567.39	2.3[b]
Sodium	209.8 ± 3.58[a]	214.5 ± 0.74[a]	13.99	14.3	1500[b]
Phosphorous	543.3 ± 5.72[a]	507.8 ± 2.36[b]	77.61	72.54	700[c]
Zinc	1.70 ± 0.29[a]	1.68 ± 0.01[a]	15.45	15.27	11[c]

[a-b]Mean ± standard deviation with different lowercase letters on the same line differed by the Student's *t*-test ($p < 0.05$) between treatments.

[a] Based on National Academies of Sciences, Engineering, and Medicine 2019. Dietary Reference Intakes, 2019. Washington, DC: The National Academies Press. Based on an adult man aged 31–50 years.

[b] Adequate Intake.

[c] Recommended Dietary Allowances.

3.5. Sensory analysis of the yogurts

The results of the sensory acceptance tests of the yogurts are shown in Table S1. The consumers assigned scores in the range of 6.16–7.50 on a 9-point scale, suggesting that they liked slightly to moderate the products. Furthermore, they assigned scores in the range of 3.29–3.45 for the purchase intention, suggesting that consumers might buy the products. This study thus proved that goat milk yogurts have adequate sensory acceptance. The addition of xique-xique jam did not impact on the sensory acceptance of the products ($p > 0.05$) indicating that alterations in color, acidity and viscosity of goat milk yogurt to which xique-xique jam had been added did not impact on its acceptance by consumers with the advantage that a yogurt with higher mineral content could be obtained.

The results of the JAR for the yogurts are shown in Table S2. The consumers assigned scores in the range of 2.51–3.37 on a 5-point scale, suggesting that they thought that the color, aroma, consistency, texture, sweetness, flavor, and acidity of the products were near the ideal. The addition of xique-xique jam did not impact on the JAR of the attributes of the products ($p > 0.05$), except for color. The dark color of the yogurt with xique-xique jam was considered less ideal than the color of the conventional product ($p < 0.05$). It is important to mention that the xique-xique jam gave an herbaceous aroma and flavor to the products, which was considered near to the ideal (scores of 2.66 and 2.89, respectively).

The results of the penalty analysis are presented in Fig. S1. The consumers considered that the conventional yogurt needed improvements in all the evaluated attributes, as it presented a color considered too white, a too high goat aroma and acidity, and too low consistency and sweetness. The yogurt with xique-xique jam needed no improvements in the color, herbaceous aroma, consistency, and herbaceous flavor. These results suggest that the herbaceous characteristics, and the lower viscosity provided by xique-xique jam were appreciated by consumers. However, more than 45% of the consumers considered that both goat milk yogurts, with and without jam, had less sweetness than the ideal, resulting in more than 1.5 points difference in overall acceptance. Furthermore, both yogurts were considered too acid and with too strong goat aroma. Therefore, it is important to consider reducing the intensity of these attributes in future products to increase their acceptance.

The results of the present study are important for the dairy industries, mainly those that process goat milk yogurt, as it demonstrated that the addition of a jam made from a cactacea widely available in Brazilian countryside could improve the nutritional value, technological properties and sensory characteristics of yogurt products, resulting in yogurts closer to a consumer's ideal yogurt.

4. Conclusion

This was the first study to use the cactus xique-xique in the development of jam, proving that xique-xique jam could improve the nutritional value and technological properties of goat milk yogurts. The xique-xique jam presented a dark yellow color, was slightly acid, and characterized by its fiber content. Furthermore, it did not present significant concentrations of antinutritional compounds (tannins, trypsin inhibitor and phytic acid). It presented potassium, magnesium, calcium, and manganese as main minerals. Finally, it presented 13 phenolic compounds, belonging to the groups of flavanols, flavonols, phenolic acids and flavanones with variable bioaccessibility. The addition of xique-xique jam resulted in yogurts with higher nutritional value (lipid, protein and mineral content), and technological properties (higher moisture content during storage, lower acidity, and reduced viscosity), with no impact on sensory acceptance or sensory characteristics. Furthermore, the consumers considered that yogurt with xique-xique jam needed no improvements in the color, herbaceous aroma, consistency, and herbaceous flavor, while the conventional yogurt needed improvements in all the evaluated attributes.

CRediT authorship contribution statement

Fabrícia França Bezerril: Conceptualization, Investigation, Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization, participated in the conceptualization of the study, performed the investigation, worked in the formal analysis of the data, wrote the original draft of the manuscript. All authors were involved in review, editing and visualization. **Marciane Magnani:** Investigation, Writing - original draft, Writing - review & editing, Visualization, Resources, Supervision, performed the investigation, wrote the original draft of the manuscript. All authors were involved in review, editing and visualization. provided the resources for development of the study and worked in the supervision. **Maria Teresa Bertoldo Pacheco:** Investigation, Writing - review & editing, Visualization, performed the investigation, All authors were involved in review, editing and visualization. **Maria de Fátima Vanderlei de Souza:** Conceptualization, Writing - review & editing, Visualization, participated in the conceptualization of the study, All authors were involved in review, editing and visualization. **Rossana Maria Feitosa Figueiredo:** Investigation, Writing - review & editing, Visualization, performed the investigation, All authors were involved in review, editing and visualization. **Marcos dos Santos Lima:** Investigation, Formal analysis, Data curation, Writing - review & editing, Visualization, performed the investigation, worked in the formal analysis of the data, All authors were involved in review, editing and visualization. **Graciele da Silva Campelo Borges:** Investigation, Formal analysis, Data curation, Writing - review & editing, Visualization, Resources, Supervision, performed the investigation, worked in the formal analysis of the data, All authors were involved in review, editing and visualization. provided the resources for development of the study and worked in the supervision. **Maria Elieidy Gomes de Oliveira:** Conceptualization, Writing - review & editing, Visualization, participated in the conceptualization of the study, All authors were involved in review, editing and visualization. **Tatiana Colombo Pimentel:** Formal analysis, Data curation, Writing - original draft, Writing - review & editing, Visualization, worked in the formal analysis of the data, wrote the original draft of the manuscript. All authors were involved in review, editing and visualization. **Rita de Cássia Ramos do Egypto Queiroga:** Conceptualization, Writing - review & editing, Visualization, Supervision, Project administration, participated in the conceptualization of the study, All authors were involved in review, editing and visualization. provided the resources for development of the study and worked in the supervision, was responsable by the project administration.

Declaration of competing interest

The authors declare no conflict of interest.

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Appendix A. Supplementary data

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