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Improving the physicochemical and sensory properties and volatile profile of goat ricotta cream with *Limosilactobacillus mucosae* CNPC007 supplementation

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A B S T R A C T

This study assessed the effects of the autochthonous strain *Limosilactobacillus mucosae* CNPC007 on the techno-functional characteristics, physicochemical properties, volatile profile, and sensory aspects of goat ricotta cream during refrigerated storage. Three cheese formulations were tested: CRC (without probiotic), RCLM (with *L. mucosae* CNPC007), and RCLA (with commercial probiotic *Lactobacillus acidophilus* La-5). *L. mucosae* CNPC007 influenced color, adhesiveness, lactose content, acidity, and proteolysis depth index in goat ricotta cream. RCLA and RCLM maintained a probiotic viable cell count >6 log CFU g^{-1}. RCLM had the highest proteolysis depth index and free amino acid release. Seventeen distinct volatile compounds were identified in the formulations. Probiotic supplementation did not affect global acceptance or purchase intention. RCLA and RCLM were preferred over CRC in the ranking test and considered ideal for goat aroma in the JAR test. *L. mucosae* CNPC007 supplementation has the potential to improve the nutritional, functional, aromatic, and sensory aspects of goat ricotta cream.

1. Introduction

Probiotics are living microorganisms that, when ingested in adequate amounts, confer health benefits to consumers (Hill et al., 2014). These microorganisms are commonly used in dairy products due to their capacity to survive exposure to gastrointestinal and storage conditions without negatively affecting the quality of these products (Lopes et al., 2021). *Lactobacillus acidophilus* La-5 is a probiotic strain commercially used in the dairy industry to obtain various products with functional claims (Grylls, Seidler, & Neil, 2021). A previous study has already reported the positive impacts of this probiotic on nutritional, technological, and sensory

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parameters in dairy product (Silva, Tagliapietra, Pivetta, & Richards, 2022b). However, the search for new strains with probiotic aptitudes, especially autochthonous probiotics, has been encouraged. Recently, the strain *Limosilactobacillus mucosae* CNPC007, isolated from goat milk, was indicated as a promising biofunctional and technological strategy for incorporation into goat dairy products since this strain has shown advantages over commercial probiotic and/or starter strains (Dantas et al., 2022; Galdino et al., 2021).

Goat milk contains oligosaccharides, short-chain fatty acids, vitamins, minerals, and high biological value proteins, as well as a high content of smaller fat globules compared to cow milk, allowing better and faster absorption by human intestinal cells (Verruck, Dantas, & Prudencio, 2019). The high nutritional value of goat milk has contributed to formulating innovative fermented dairy products, such as yogurt (Morais et al., 2022), ice cream (Oliveira, Almeida, Santos, & Dias, 2021), kefir (Wang & Guo, 2023), drinks (Garay et al., 2021; Liu et al., 2024), and cheeses (Kavas et al., 2021; Lopes et al., 2021). Goat dairy products, especially cheeses and cream cheese, are good probiotic carriers primarily due to their high pH and low oxygen content (Silva et al., 2022a).

Goat ricotta cream is produced with the homogenization of goat ricotta cheese with salt, spices, and other ingredients, such as milk cream and polysaccharide gums, achieving a soft and spreadable texture (Buriti, Cardarelli, Filisetti, & Saad, 2007), emerging as an excellent probiotic carrier with high supplemented probiotic viable counts during cold storage and the capability of protecting probiotic cells during gastrointestinal digestion (Meira et al., 2015). However, the distinct sensory characteristics of goat ricotta cream, particularly its odor and flavor, have commonly negatively impacted the acceptance by some consumers. This prompts exploring innovative technological strategies to improve consumer acceptance of goat ricotta cream, such as supplementing with selected probiotic strains (Bezerril et al., 2022). Probiotic cultures often produce volatile compounds contributing to taste and aroma, resulting in goat dairy products with minimized intensities of the perceived unpleasant aroma, which could be recognized as a negative sensory feature by some consumers (Bezerril et al., 2022).

Given the increasing demand for novel probiotic foods, the distinct nutritional quality of goat milk and derived products, and the need to minimize or mitigate their specific goat sensory attributes (Morais et al., 2022), this study developed a goat ricotta cream supplemented with *L. mucosae* CNPC007 and evaluated the impacts of this strain on techno-functional, physicochemical, and sensory characteristics and volatile profile during refrigerated storage.

2. Material and methods

2.1. Raw materials

Goat milk and butter (pasteurized at 65 °C for 30 min) used to produce goat ricotta cream were obtained from a Rural Producers Cooperative (Monteiro, PB, Brazil). The commercial coagulating agent (HA-LA liquid coagulant, microbial chymosin – *Aspergillus niger* var *awamori*, coagulant power 1:3000/75 IMCU) used to produce the goat milk whey was obtained from Christian Hansen® (Valinhos, MG, Brazil). Calcium chloride ($CaCl_2$) P.A. was obtained from FMaia® Ltda (Cotia, SP, Brazil). The autochthonous *Limosilactobacillus mucosae* CNPC007 strain was obtained from the "Collection of Microorganisms of Interest to the Food and Agroenergy Industry" of Embrapa Agroindustry Tropical (Fortaleza, CE, Brazil), and it was cultivated and freeze-dried as previously described (Moraes et al., 2017; Moraes, Santos, Barcelos, Lopes, & Egito, 2018).

The commercial probiotic freeze-dried *Lactobacillus acidophilus* La-5 strain was obtained from Christian Hansen® (Valinhos, MG, Brazil).

2.2. Preparation of the inoculum and goat milk whey

Freeze-dried cultures of *L. mucosae* CNPC007 and *L. acidophilus* La-5 (positive control) were added separately at a concentration of 0.1% (w/v) in reconstituted powdered whole goat milk (Caprilat®, Governador Valadares, MG, Brazil) at 13% (w/v) in sterilized water, cooled to 35 ± 0.5 °C, and incubated at 37 ± 0.5 °C under aerobiosis for 22 h (stationary phase). To determine the viable cell counts of *L. mucosae* CNPC007 and *L. acidophilus* La-5, an aliquot of the inoculum was taken, serially diluted (1:9 v/v, 10^{-1} to 10^{-9}) in sterilized peptone water (HiMedia, Mumbai, India) at 0.1% (w/v), inoculated in de Man, Rogosa, and Sharpe agar (MRS, HiMedia) acidified to pH 5 (IDF, 1995) and MRS (HiMedia) with no acidification, respectively. The plates were incubated at 37 ± 0.5 °C for 48–72 h under aerobic and anaerobic conditions (Anaerogen System Anaerogen, Oxoid) for counting *L. mucosae* CNPC007 and *L. acidophilus* La-5 viable cells, respectively. The final viable cell count of *L. mucosae* CNPC007 and *L. acidophilus* La-5 in the inocula used for goat ricotta cream processing was >8 log CFU mL^{-1}.

2.3. Production of goat ricotta cream

The goat milk whey was initially obtained following a previously described procedure (Oliveira, Garcia, Queiroga, & Souza, 2012). Goat ricotta cream formulations were produced from goat milk whey and other ingredients, as shown in Fig. 1 (Fritzen-Freire et al., 2013; Meira et al., 2015). The inoculum containing the tested probiotic strain was incorporated in the final step of mixing the ingredients at a concentration of 0.1% (w/w) of the total mass of the goat ricotta cream produced. Three goat ricotta cream formulations were prepared: CRC (control ricotta cream without probiotic, as a negative control), RCLM (gat ricotta cream supplemented with *L. mucosae* CNPC007), and RCLA (goat ricotta cream supplemented with *L. acidophilus* La-5, as a positive control). The goat ricotta cream formulations obtained were packaged in plastic cups (100 mL capacity), sealed with aluminum foil lids, and stored at 4 ± 0.5 °C.

The formulations were processed in three independent experiments. The technological, physicochemical, and microbiological parameters were analyzed on days 1, 14, and 28 of refrigerated storage (4 ± 0.5 °C). The volatile profile was determined on days 1 and 14 of refrigerated storage. Sensory analyses, including sensory acceptance, purchase intention, and JAR (Just About Right) tests, were performed on day 7 of refrigerated storage, and the PAE (Preferred Attribute Elicitation) test was performed on days 1, 7, and 14 of refrigerated storage.

2.4. Determination of physical and physicochemical parameters of goat ricotta cream

The goat ricotta cream was evaluated for water activity (a_w) (Aqualab®, model CX-2, Washington, USA), pH (Tecnal®, model Meter Tec-2, Piracicaba, SP, Brazil), titratable acidity (TA), moisture, total solids, ash, and protein contents using standard procedures (AOAC, 2019). Lipid contents were determined as described by Folch, Lees, and Stanley (1957).

2.5. Determination of lactose content and organic acid profile of goat ricotta cream

The contents of lactose and organic acids (propionic, acetic, lactic, and citric acid) were determined with high-performance

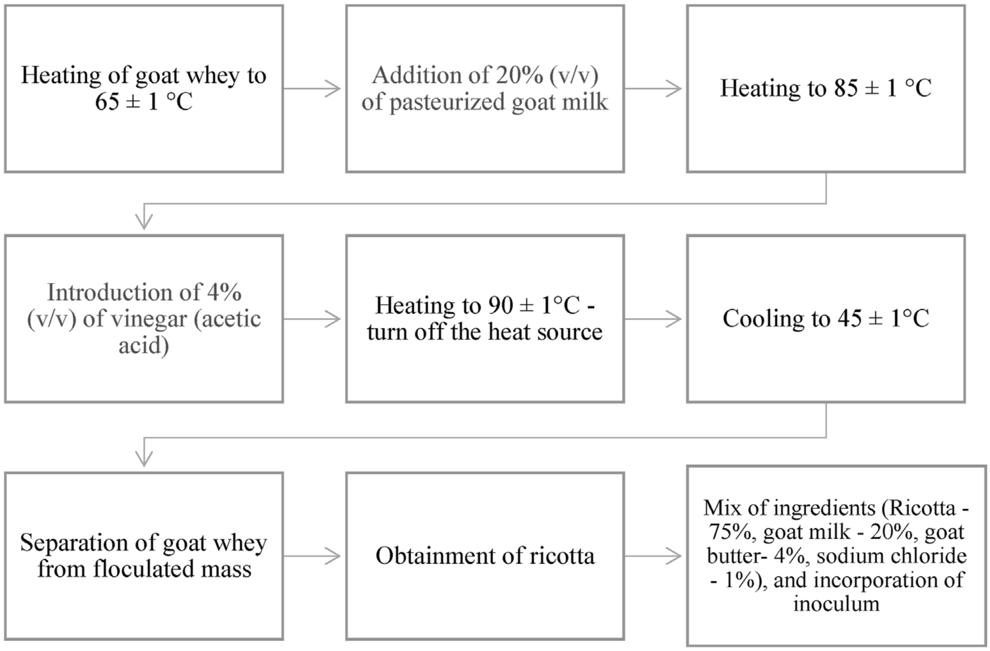

Fig. 1. Flowchart of the processes for manufacturing goat ricotta cream formulations.

liquid chromatography (HPLC) technique using an Agilent® chromatograph (model 1260 Infinity LC, Agilent Technologies, Santa Clara, CA, USA) as previously described (Ball, Bullock, Lloyd, & Mapp, 2011). The data were processed using OpenLAB CDS ChemStation EditionTM software (Agilent Technologies®). The lactose standard was obtained from Sigma–Aldrich (St. Louis, MA, USA), the organic acid standards were obtained from Vetec Química Fina (Rio de Janeiro, RJ, Brazil) (purity $\geq$ 99%), and ultrapure water was obtained using a MilliQ® system (EMD Millipore). The results were expressed in mg per 100 g (mg 100 g^{-1}).

2.6. Determination of protein profile of goat ricotta cream

The protein profile was determined through soluble protein concentration using the Bradford method (1976), proteolysis index (extent and depth) according to Andreatta et al. (2007) and AOAC (2019), electrophoretic profile of the proteins using the technique described by Laemmli (1970), and free amino acids determined as previously described (Hagen, Frost, & Augustin, 1989; White, Hart, & Fry, 1986).

2.7. Determination of volatile profile of goat ricotta cream

Volatile compounds were extracted with the HS-SPME technique (Bezerra et al., 2017) using a 50/30 μm divinylbenzene/carboxen/polydimethylsiloxane (DVB/CAR/PDMS) fiber (Supelco, Bellefonte, PA, USA). Twenty g of cheese were transferred to a 100 mL flat-bottomed headspace flask with a PTFE/silicone septa magnetic seal and cap, and the volatile compounds were extracted by placing the flask in a water bath at 40 °C with internal magnetic stirring. The sample reached equilibrium in 20 min, being exposed to the fiber for 40 min. A 7890B gas chromatograph (GC) coupled to an Agilent Technologies 5977B mass spectrometer (Little Falls, DE, USA) and a VF-5MS column (30 m $\times$ 0.25 mm $\times$ 0.25 μm) and previously described analytical conditions were used to separate and identify the volatile compounds collected by SPME (Bezerril et al., 2022). Data were acquired and analyzed using the Mass Hunter (Agilent) software program. The linear retention index (LRI) of each compound was calculated using the retention times of a homologous series of C6–C25 n-alkanes. The volatile components were identified by comparing their mass spectra and LRI values with the NIST 2014 computer database (Version 2.2 2014). The results were expressed as AU $\times$ 10^5, where AU = arbitrary units.

2.8. Determination of technological parameters of goat ricotta cream

The yield of goat ricotta cream was determined as previously described (Zeng, Sorval, Fekadu, Bah, & Popham, 2007) and expressed as the fresh weight of the cheese obtained from each liter of the milk and whey mixture used for production (g of cheese per L of whey and milk). Instrumental textural analysis (hardness, springiness, adhesiveness, cohesiveness, gumminess, and chewiness) was determined using a TA-XT2® texturometer (Stable Micro Systems, Haslemere, UK) as previously described (Borba et al., 2014). The color analysis was determined considering the CIELAB colorimetric space, defined by L*, a*, b*, using a CR-300 colorimeter® (New Jersey, USA) according to the International Commission on Illumination (CIE, 1996). The L* coordinate corresponds to luminosity, while a* and b* refer to the green (−)/red(+), and blue(−)/yellow(+) chromaticity coordinates, respectively.

2.9. Microbiological analyses of goat ricotta cream

The hygienic-sanitary condition was assessed based on the viable cell counts of coagulase-positive *Staphylococcus* and *Escherichia coli*, as well as the detection of *Salmonella* spp. following standard procedures (APHA, 2015). For determination of viable cell counts of *L. mucosae* CNPC007 and *L. acidophilus* La-05, 25 g of goat ricotta cream was diluted in 225 mL of sterile peptone water (0.1 g 100 g^{-1}) (HiMedia), serial dilutions were made (1:9 v/v, 10^{-1}–10^{-9}), and 10 μL of each dilution were inoculated on MRS agar (HiMedia) acidified to pH 5.0 and MRS with no acidification, and incubated (37 ± 0.5 °C, 48–72 h) under aerobiosis and anaerobiosis (Anaerogen) (Moraes et al., 2018) to count *L. mucosae* CNPC007 and

L. acidophilus La-5 viable cells, respectively. The results were expressed in log CFU g^{-1}.

2.10. Sensory analyses of goat ricotta cream

The research was approved by an Ethics Committee on Human Research (Health Sciences Center, Federal University of Paraíba; protocol number 3.853.726) recognized by the Brazilian National Research Ethics Commission. The ricotta cream formulations were subjected to descriptive sensory tests using untrained panelists, to cite: JAR (Just About Right) or Ideal Scaling, sensory acceptance tests, purchase intention, ordering preference (Stone & Sidel, 2004), and PAE (Preferred Attribute Elicitation) (Silva, Barão, Esmerino, Cruz, & Pimentel, 2021).

A total of 60 untrained panelists, including men and women between 18 and 45 years old, participated in the JAR tests, sensory acceptance, purchase intention, and preference ranking. These panelists were selected based on their habits and interest in consuming goat dairy products and reported not having health issues related to milk protein allergy and/or lactose intolerance or any physical impairment that affects the sensory evaluation, specifically related to smell, taste, and sight. For the PAE test, the panel comprised five women and two men between 30 and 45 years old selected according to their habit of consuming goat cheese.

JAR and Ideal Scale tests were performed to measure the ideal amount of a certain component that should be present in the product. Panelists evaluated the samples by recording their responses on specific scales (Ideal Scale), identifying how ideal such a sample was in relation to a given attribute under study (Vickers, 1988).

The sensory acceptance test evaluated the appearance, color, aroma, taste, texture, and global acceptance. The panelists assigned values to the samples using a structured hedonistic scale with nine points (1 = disliked very much; 5 = neither liked nor disliked; 9 = liked very much). The forms contained fields allowing the panelists to write descriptions considered important. Examined products were considered accepted when obtaining an average $\geq$ 5.0 (equivalent to the hedonic term "I moderately liked it"). Purchase intention was evaluated using a structured hedonic scale with five points (1 = would never buy; 3 = maybe would buy/maybe not buy; 5 = would buy). The relative preference among the cheese samples was evaluated using an ordering design in randomized blocks of 60 panelists using a preference test with scores ranging from 1 ("most preferred sample") to 3 ("least preferred sample").

The PAE test was conducted as previously described (Bezerril et al., 2022) to evaluate the correlation matrix of the perception of panelists in relation to a specific characteristic of the product, considering aroma (fermented, goat, normal, and dairy) and flavor (acid, salty, goaty, and normal).

2.11. Statistical analysis

The experiments were performed in triplicate on three independent occasions. The results were expressed as average ± standard deviation. The Kolmogorov–Smirnov normality test was performed to verify the normal distribution of data. Data were submitted to the Student's t-test or analysis of variance (ANOVA) followed by Tukey's test, considering a p-value of $\leq$0.05 for significance. These statistical analyses were performed with SigmaStat software (version 3.5, Jandel Scientific Software, San Jose, California).

The data obtained in the Ideal Scale affective test were evaluated by penalty analysis, which shows penalties (average drops in overall taste) for each non-JAR attribute in each sample. Non-JAR attributes with statistically significant penalties are highlighted with an "*" in the penalty analysis graphs (Nguyen & Wismer, 2019). The ordering-preference sensory tests were analyzed according to the Friedman test, using the Newell MacFarlane Table (Stone & Sidel, 2004). Sensory data obtained by the PAE method were submitted to a Principal Component Analysis (PCA) to generate graphical representations of research objects or variables reflecting their proximity. These statistical analyses were performed using GraphPad Prism 9.0 software.

3. Results and discussion

3.1. Physical and physicochemical parameters of goat ricotta cream

Table 1 shows the physical and physicochemical parameters of examined goat ricotta cream formulations. The moisture values ranged from 68.56 to 71.80 g 100 g^{-1}, agreeing with the Brazilian legislation requirements (Brazil, 2020). Moisture values did not change in CRC and RCLM during storage ($p > 0.05$). RCLA had the highest moisture on day 28 of storage ($p \leq 0.05$).

As expected for fermented dairy products, an increase in acidity and a reduction in pH ($p \leq 0.05$) were observed in goat ricotta cream formulations during storage. RCLM and RCLA had the greatest increase in acidity during storage ($p \leq 0.05$). RCLM and RCLA had lower lactose contents ($p \leq 0.05$) compared to CRC at the end of storage (Table 1), which could be linked to the action of lactic acid bacteria and/or probiotics converting lactose into lactic acid and directing a higher acidity and lower pH (Lopes et al., 2021).

There was an increase in protein content during storage in RCLA ($p \leq 0.05$), and an increase in lipid content in CRC and RCLM ($p \leq 0.05$) (Table 1). RCLA had the higher protein content on day 28 of storage, while RCLM had higher lipid content ($p \leq 0.05$). Biochemical changes, such as protein hydrolysis (proteolysis) and fat hydrolysis (lipolysis), can occur due to the action of enzymes present in milk or rennet, starter cultures, non-starter bacteria, and secondary microorganisms (Kondily, Pappa, Bosnea, Vlachou, & Malamou, 2023). The increase in lipid content during storage may be associated with the interaction between the goat ricotta cream and *L. mucosae* CNPC007, which can produce enzymes, such as lipases that hydrolyze lipids into fatty acids and glycerol, leading to an increase in lipid content.

3.2. Lactose and organic acid contents of goat ricotta cream

Table 2 shows the contents of lactose and organic acids in examined goat ricotta cream formulations during storage. Consistent with the acidity and pH results, the lactose content decreased in all formulations during storage, indicating lactose consumption over time, particularly in RCLA and RCLM ($p \leq 0.05$). Concomitant with the lactose consumption, there was a higher production of lactic acid ($p \leq 0.05$), which emerged as the predominant organic acid, mostly in RCLA and CRC on day 28 of storage ($p \leq 0.05$). Lactic acid is formed from the metabolism of starter and/or probiotic cultures during fermentation (Bezerril et al., 2021).

Short-chain fatty acids (SCFA) synthesis is a characteristic of the probiotic fermentation activity (Nagpal et al., 2018). Lactic, propionic, and acetic acids were among the most predominant organic acids in examined goat ricotta cream formulations. Propionic acid is a SCFA with an important role in stimulating ATP production (Singh, Vishwakarma, & Singhal, 2018), besides inhibiting cholesterol synthesis. An early study reported that probiotic *Lactobacillus* and *Enterococcus* strains could produce SCFA, including propionic and butyric acids (Nagpal et al., 2018), which could offer advantages to individuals with diabetes, obesity, and autoimmune disorders, which are conditions linked to a decreased production of SCFA by the

Table 1
Results (average ± standard deviation; n: 9) of physical and physicochemical parameters of goat ricotta cream formulations during 28 days of refrigerated storage.[a]

Parameters	Storage time (days)	Goat ricotta formulations		
		CRC	RCLM	RCLA
a_w	1	0.92 ± 0.01^{Aa}	0.92 ± 0.01^{Aa}	0.92 ± 0.01^{Aa}
	14	0.92 ± 0.01^{Aa}	0.91 ± 0.01^{Aa}	0.92 ± 0.01^{Aa}
	28	0.91 ± 0.01^{Aa}	0.92 ± 0.01^{Aa}	0.92 ± 0.01^{Aa}
pH	1	6.80 ± 0.04^{Aa}	6.71 ± 0.01^{Aa}	6.15 ± 0.42^{Aa}
	14	5.50 ± 0.06^{Bb}	5.24 ± 0.01^{Cb}	5.72 ± 0.06^{Aa}
	28	5.27 ± 0.03^{Ac}	5.02 ± 0.03^{Cc}	5.19 ± 0.01^{Bb}
Titratable acidity as lactic acid (g 100 g^{-1})	1	0.26 ± 0.01^{Ac}	0.32 ± 0.02^{Ac}	0.33 ± 0.01^{Ac}
	14	0.34 ± 0.01^{Cb}	0.94 ± 0.01^{Ab}	0.41 ± 0.01^{Bb}
	28	0.38 ± 0.01^{Ca}	1.24 ± 0.02^{Aa}	0.52 ± 0.01^{Ba}
Moisture (g 100 g^{-1})	1	68.84 ± 0.18^{Ba}	68.56 ± 0.03^{Ca}	70.92 ± 0.05^{Ab}
	14	68.75 ± 0.54^{Aa}	69.06 ± 0.40^{Aa}	70.34 ± 0.29^{Ab}
	28	68.86 ± 0.55^{Ba}	68.58 ± 0.40^{Ba}	71.80 ± 0.05^{Aa}
Ash (g 100 g^{-1})	1	1.59 ± 0.05^{Ca}	1.89 ± 0.01^{Ba}	2.03 ± 0.01^{Aa}
	14	1.60 ± 0.02^{Ba}	1.66 ± 0.06^{Bb}	1.97 ± 0.01^{Aa}
	28	1.63 ± 0.02^{Ca}	1.77 ± 0.02^{Bab}	2.00 ± 0.05^{Aa}
Protein (g 100 g^{-1})	1	8.85 ± 0.42^{Aa}	9.13 ± 0.07^{Aa}	7.72 ± 0.03^{Bb}
	14	9.03 ± 0.04^{Aa}	8.59 ± 0.26^{Aa}	7.64 ± 0.38^{Bb}
	28	$8.97 \pm 0.11A^{Ba}$	8.35 ± 0.43^{Ba}	10.44 ± 0.49^{Aa}
Lipid (g 100 g^{-1})	1	13.88 ± 0.13^{Cc}	15.90 ± 0.13^{Ab}	15.08 ± 0.11^{Ba}
	14	15.39 ± 0.13^{Aa}	14.94 ± 0.14^{Ac}	15.18 ± 0.52^{Aa}
	28	14.53 ± 0.13^{Cb}	17.12 ± 0.09^{Aa}	15.86 ± 0.23^{Ba}

[a] Goat ricotta cream formulations: CRC – control ricotta cream; RCLM – Ricotta cream supplemented with *L. mucosae* CNPC007; RCLA – Ricotta cream supplemented with *L. acidophilus* La-5. A–C: different capital letters in the same row denote differences ($p \le 0.05$) between distinct formulations at the same storage time, according to Tukey's test. a–c: different superscript letters in the same column denote differences ($p \le 0.05$) between the distinct storage times for the same formulation, according to Tukey's test.

intestinal microbiota (Mesnage, Antoniou, Tsoukalas, Goulielmos, & Tsatsakis, 2018). Acetic acid in ricotta cheese may result from bacterial fermentation or adding this acid during processing, but the acetic acid content remained constant in the examined goat ricotta cream formulations during storage ($p > 0.05$).

3.3. Protein profile of goat ricotta cream

Table 3 shows the concentration of soluble proteins and proteolysis index in extension and depth in the examined goat ricotta cream formulations on days 1 and 28 of refrigerated storage. The soluble protein content was increased in RCLA on day 28 of refrigerated storage, while reduced in CRC and RCLM ($p \le 0.05$).

The proteolysis index increased in both extent and depth during storage, mainly in RCLM and RCLA ($p \le 0.05$). The extent of proteolysis is related to the activity of enzymes in the coagulating agents and microbial enzymes used to make cheese, which degrade proteins into high molecular weight peptides (Xia et al., 2022). The depth of proteolysis is related to the presence of low molecular weight substances due to proteolytic enzymes degrading casein peptides into smaller peptides and free amino acids (Bezerra et al., 2016).

No enzyme acting as a coagulating agent is used to produce ricotta cream, although a residual presence of chymosin can occur since this enzyme is used to manufacture the rennet or curd cheese, a process from which the goat whey used in this study was obtained. The amount of chymosin (rennet) used to produce the goat ricotta cream was the same for all formulations, and the differences observed in the protein profile between RCLM and RCLA could be probably related to enzymes produced by the supplemented probiotic strains rather than to rennet activity. RCLA and RCLM had the highest proteolysis index in depth on day 28 of storage ($p \le 0.05$).

Table 2
Contents (average ± standard deviation; n: 9) of lactose and organic acids of goat ricotta cream formulations during 28 days of refrigerated storage.[a]

Parameters (g 100 g^{-1})	Storage time (days)	Goat ricotta formulations		
		CRC	RCLM	RCLA
Lactose	1	2.42 ± 0.43^{ABa}	2.50 ± 0.14^{Aa}	2.32 ± 0.11^{Ba}
	14	0.93 ± 0.10^{Ab}	0.83 ± 0.07^{Ab}	0.52 ± 0.11^{Ab}
	28	0.79 ± 0.01^{Ab}	0.30 ± 0.02^{Cc}	0.48 ± 0.02^{Bb}
Acetic acid	1	0.01 ± 0.00^{Ab}	0.02 ± 0.00^{Aa}	0.02 ± 0.01^{Aa}
	14	0.05 ± 0.02^{Aa}	0.01 ± 0.00^{Aa}	0.02 ± 0.01^{Aa}
	28	0.06 ± 0.0^{Aa}	0.01 ± 0.00^{Ab}	0.03 ± 0.02^{Aa}
Citric acid	1	0.02 ± 0.00^{A}	0.07 ± 0.00^{A}	0.03 ± 0.00^{A}
	14	<LOD	<LOD	<LOD
	28	<LOD	<LOD	<LOD
Lactic acid	1	0.47 ± 0.00^{Ac}	0.15 ± 0.03^{Bb}	0.05 ± 0.02^{Cb}
	14	0.93 ± 0.01^{Ab}	$0.92 \pm 0.^{07Aa}$	0.62 ± 0.21^{Bab}
	28	1.44 ± 0.01^{Aa}	0.61 ± 0.17^{Ba}	1.30 ± 0.37^{Aa}
Propionic acid	1	0.68 ± 0.30^{Aa}	0.74 ± 0.17^{Aa}	0.53 ± 0.02^{Aa}
	14	0.21 ± 0.00^{Aa}	0.37 ± 0.10^{Aab}	0.13 ± 0.03^{Aa}
	28	0.53 ± 0.02^{Aa}	0.13 ± 0.05^{Ab}	0.33 ± 0.17^{Aa}

[a] Formulations: CRC – control ricotta cream; RCLM – Ricotta cream supplemented with *Lactobacillus mucosae* CNPC007; RCLA – Ricotta cream supplemented with *Lactobacillus acidophilus* La-5. <LOD: below the limit of detection. A–C: different capital letters in the same row denote differences ($p \le 0.05$) between the formulations at the same time during storage, according to Tukey's test. a–c: different superscript letters in the same column denote differences ($p \le 0.05$) between the same formulation at distinct storage times during storage, according to Tukey's test.

Table 3
Results (average ± standard deviation; n: 9) of soluble protein, extent of proteolysis index (EPI), and depth of proteolysis index (DPI) of goat ricotta cream formulations during 28 days of refrigerated storage.[a]

Parameters	Time of storage (days)	Goat ricotta cream formulations		
		CRC	RCLM	RCLA
Soluble protein (μg mg^{-1})	1	4.18 ± 0.01^{Ba}	4.35 ± 0.08^{Aa}	2.82 ± 0.05^{Cb}
	28	3.14 ± 0.01^{Cb}	3.91 ± 0.07^{Bb}	4.21 ± 0.08^{Aa}
EPI (%)	1	3.01 ± 0.13^{Aa}	1.98 ± 0.01^{Cb}	2.31 ± 0.02^{Bc}
	14	2.96 ± 0.01^{Ba}	2.11 ± 0.10^{Cb}	2.85 ± 0.08^{Ab}
	28	2.82 ± 0.04^{Ca}	3.16 ± 0.09^{Ba}	4.29 ± 0.02^{Aa}
DPI (%)	1	1.75 ± 0.08^{Cb}	1.92 ± 0.01^{Bb}	3.39 ± 0.03^{Ac}
	14	1.96 ± 0.02^{Ba}	2.06 ± 0.10^{Bb}	3.52 ± 0.01^{Ab}
	28	2.02 ± 0.01^{Ba}	5.24 ± 0.16^{Aa}	5.32 ± 0.03^{Aa}

[a] Formulations: CRC – control ricotta cream; RCLM – Ricotta cream supplemented with *Lactobacillus mucosae* CNPC007; RCLA – Ricotta cream supplemented with *Lactobacillus acidophilus* La-5. A–C: different capital letters in the same row denote differences (p ≤ 0.05) between the formulations at the same time during storage, according to Tukey's test. a–c: different superscript letters in the same column denote differences (p ≤ 0.05) between the same formulation at distinct storage times during storage, according to Tukey's test or Student's t-test.

This was probably due to the action of microbial enzymes causing the release of medium and small molecular weight peptides and free amino acids. Similar results were found for goat curd cheese supplemented with *L. acidophilus* La-05 during 21 days of storage (Oliveira et al., 2012), while higher proteolysis rates (both extent and depth) were found for goat cheese during a more prolonged storage period (180 days) (Bontinis, Mallatou, Pappa, Massouras, & Alichanidis, 2012). The goat ricotta cream formulations examined in this study were fresh or minimally ripened (28 days of storage), and the measured storage period was not sufficiently long to induce more pronounced proteolysis.

The electrophoretic profile of examined goat ricotta cream formulations on days 1 and 28 of refrigerated storage is shown in Fig. 2. Casein fractions (αs2-casein 25.23 kDa), α-lactoalbumin (14 kDa), β-lactoglobulin (18 kDa), dimers of β-lactoglobulin (36 kDa), serum albumin (66.33 kDa), and lactoferrin (80 kDa) were identified in goat ricotta cream, which agrees with previous results reported for goat whey proteins (Campos et al., 2022) and coalho goat cheese supplemented with *L. acidophilus* La-05 (Bezerra et al., 2016). It is impossible to affirm the occurrence of a change in the amount of the identified protein fractions. However, the electrophoretic profile image suggests an increase in high molecular weight peptides (12–20 kDa) on day 28 of storage in all examined goat ricotta cream formulations, indicating an increase in depth of proteolysis.

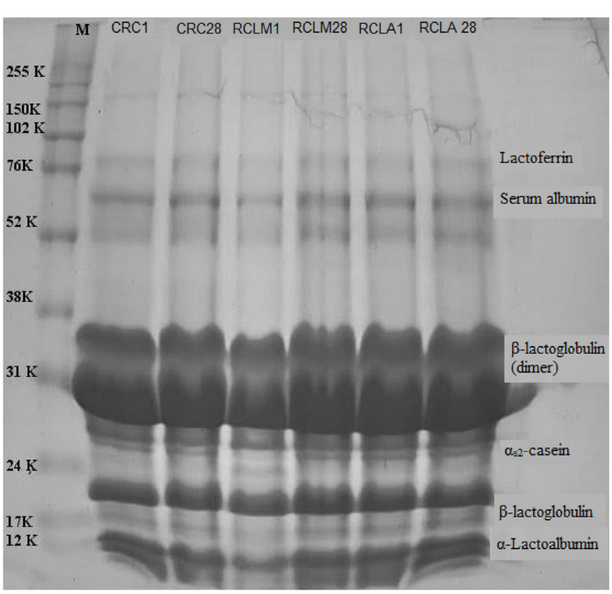

Fig. 2. Electropherograms (SDS-PAGE) of goat ricotta cream formulations during 28 days of refrigerated storage.

Ricotta, the main ingredient in ricotta cream, is a cheese made from whey with up to 20% skimmed milk per whey volume, and significant amounts of whey proteins are therefore expected in this product. Casein, although not the main protein in goat ricotta cream, is found in goat milk and goat whey used to produce this product as casein macropeptides (Campos et al., 2022), which could justify its presence in the electrophoresis profile.

Overall, most of the free amino acids in CRC decreased during storage (p ≤ 0.05) (Table 4). Conversely, the concentration of glutamic acid, alanine, and proline increased in RCLM during storage, while the concentration of glutamic acid, arginine, tyrosine, and phenylalanine increased in RCLA (p ≤ 0.05). These results agree with the depth of proteolysis, which was higher in RCLA and RCLM than in CRC. The increase in total free amino acids (TFAA) in goat ricotta cream formulations during storage also agrees with the results of a previous study with goat cheese prepared with animal and vegetable rennet (Abellán et al., 2012).

RCLM had higher amounts (p ≤ 0.05) of the essential amino acids threonine, lysine, phenylalanine, isoleucine, methionine, leucine, and of the non-essential amino acids histidine and tyrosine on day 28 of storage. RCLA had higher amounts (p ≤ 0.05) of the essential amino acids phenylalanine, valine, and methionine, as well as of the non-essential amino acids arginine, glutamic acid, proline, glycine, cysteine, and alanine. Leucine, together with the other branched-chain amino acids (such as valine), aromatic amino acids (phenylalanine and tyrosine), and methionine, constitute the main aromatic compound precursors in cheese (Yvon & Rijnen, 2001). Arginine, a conditionally essential amino acid, assists in pressure regulation and improves physical performance since it is a nitric oxide precursor (Apolzan et al., 2022). The concentration of these amino acids was higher in RCLA and RCLM than in CRC, especially in RCLM, which had a greater number and higher concentrations of essential amino acids at the end of the measured storage period.

3.4. Volatile profile of goat ricotta cream

The cheese microbiota is important in forming volatile compounds as metabolites from the microbial enzymatic breakdown of different molecules, such as proteins, lactose, lipids, lactic, and citric acid (Kavas et al., 2021). These reactions continue during cheese ripening and storage (Ramírez-López & Vélez-Ruiz, 2018). Seventeen volatile compounds were identified in RCLA, RCLM, and CRC on day 14 of storage: seven ketones, two aldehydes, four acids,

Table 4
Results (average ± standard deviation; n: 9) of free amino acids (TFAA) of goat ricotta cream formulations during 28 days of refrigerated storage.[a]

Free amino acids (mg 100 g^{-1})	Time of storage (days)	Goat ricotta formulations		
		CRC	RCLM	RCLA
Aspartic acid	1	20.44 ± 0.17^{Ab}	1.63 ± 0.01^{Ba}	1.41 ± 0.21^{Ba}
	14	24.18 ± 0.83^{Aa}	1.19 ± 0.27^{Bb}	0.54 ± 0.01^{Cb}
	28	18.72 ± 0.38^{Ac}	1.03 ± 0.04^{Bb}	0.27 ± 0.08^{Cb}
Glutamic acid	1	11.19 ± 0.01^{Aa}	10.69 ± 0.09^{Bc}	9.78 ± 0.11^{Cb}
	14	7.66 ± 0.70^{Cb}	11.97 ± 0.05^{Bb}	16.18 ± 0.95^{Aa}
	28	2.22 ± 0.08^{Cc}	18.35 ± 0.49^{Aa}	15.40 ± 0.15^{Ba}
Serina	1	11.68 ± 0.01^{Aa}	4.67 ± 0.30^{Ba}	3.34 ± 0.47^{Ca}
	14	7.74 ± 0.07^{Ab}	2.97 ± 0.05^{Bb}	2.63 ± 0.50^{Bb}
	28	6.91 ± 0.04^{Ac}	2.09 ± 0.13^{Bc}	2.20 ± 0.30^{Bb}
Glycine	1	10.52 ± 0.59^{Ba}	13.01 ± 0.20^{Aa}	2.71 ± 0.16^{Ca}
	14	10.06 ± 0.03^{Ba}	12.97 ± 0.04^{Aa}	3.27 ± 0.63^{Ca}
	28	3.26 ± 0.01^{Bb}	12.01 ± 0.01^{Ab}	3.42 ± 0.28^{Ba}
Histidine	1	31.35 ± 0.49^{Ba}	<LOD	47.85 ± 0.49^{Aa}
	14	29.13 ± 0.71^{Bb}	<LOD	38.48 ± 0.22^{Ab}
	28	28.84 ± 0.02^{Bb}	<LOD	38.16 ± 0.08^{Ab}
Arginine	1	1.97 ± 0.16^{Cc}	17.34 ± 0.83^{Ac}	16.44 ± 0.08^{Ba}
	14	13.48 ± 0.74^{Cb}	19.28 ± 0.39^{Ab}	16.78 ± 0.45^{Ba}
	28	15.42 ± 0.11^{Ba}	21.79 ± 0.30^{Aa}	15.14 ± 0.20^{Bb}
Threonine	1	11.10 ± 0.13^{Ba}	6.39 ± 0.04^{Ca}	13.81 ± 0.64^{Aa}
	14	10.15 ± 0.06^{Bb}	4.81 ± 0.28^{Cb}	12.47 ± 0.31^{Ab}
	28	9.95 ± 0.06^{Bb}	4.88 ± 0.17^{Cb}	12.26 ± 0.21^{Ab}
Alanine	1	5.96 ± 0.25^{Ba}	7.05 ± 0.19^{Aa}	0.81 ± 0.01^{Cb}
	14	2.40 ± 0.06^{Cb}	6.20 ± 0.28^{Ab}	4.30 ± 0.18^{Ba}
	28	1.44 ± 0.01^{Cc}	6.03 ± 0.04^{Ab}	4.38 ± 0.06^{Ba}
Proline	1	8.81 ± 0.02^{Bb}	19.34 ± 0.77^{Aa}	1.89 ± 0.13^{Cc}
	14	10.63 ± 0.46^{Ba}	18.06 ± 0.17^{Ab}	6.55 ± 0.08^{Cb}
	28	11.30 ± 0.14^{Ba}	16.34 ± 0.37^{Ac}	6.83 ± 0.07^{Ca}
Tyrosine	1	9.54 ± 0.11^{Ca}	0.75 ± 0.19^{Cc}	29.81 ± 0.55^{Aa}
	14	8.37 ± 0.08^{Bb}	8.16 ± 0.25^{Bb}	29.93 ± 0.59^{Aa}
	28	7.72 ± 0.14^{Bc}	10.70 ± 0.22^{Ba}	31.67 ± 3.17^{Aa}
Valina	1	4.12 ± 0.57^{Aa}	3.50 ± 0.25^{Aa}	1.53 ± 0.11^{Ba}
	14	2.55 ± 0.15^{Ab}	2.12 ± 0.17^{Ab}	1.44 ± 0.10^{Ba}
	28	<LOD	1.29 ± 0.01^{Ac}	0.59 ± 0.02^{Bb}
Methionine	1	4.04 ± 0.98^{Ba}	0.73 ± 0.19^{Ca}	7.15 ± 0.04^{Aa}
	14	0.16 ± 0.05^{Cb}	0.88 ± 0.17^{Ba}	4.44 ± 0.34^{Ab}
	28	0.07 ± 0.01^{Bb}	1.00 ± 0.13^{Aa}	0.83 ± 0.17^{Ac}
Cystine	1	5.54 ± 0.38^{Ba}	10.37 ± 0.08^{Aa}	4.60 ± 0.14^{Ca}
	14	5.97 ± 0.04^{Ba}	10.26 ± 0.36^{Aa}	2.34 ± 0.08^{Cb}
	28	0.88 ± 0.02^{Cb}	10.17 ± 0.23^{Aa}	2.11 ± 0.17^{Bb}
Isoleucine	1	3.41 ± 0.43^{Aa}	<LOD	1.13 ± 0.39^{Ba}
	14	1.66 ± 0.01^{Ab}	<LOD	1.15 ± 0.12^{Aa}
	28	0.89 ± 0.32^{Ab}	<LOD	1.52 ± 0.12^{Aa}
Leucine	1	7.40 ± 0.47^{Aa}	2.21 ± 0.28^{Ca}	5.72 ± 0.25^{Ba}
	14	0.72 ± 0.03^{Cb}	2.00 ± 0.01^{Ba}	3.76 ± 0.23^{Ab}
	28	0.12 ± 0.01^{Bb}	0.03 ± 0.04^{Cb}	0.47 ± 0.07^{Ac}
Phenylalanine	1	6.59 ± 0.11^{Aa}	1.38 ± 0.08^{Cc}	3.58 ± 0.40^{Ba}
	14	2.56 ± 0.01^{Cb}	3.06 ± 0.08^{Bb}	4.12 ± 0.54^{Aa}
	28	1.87 ± 0.04^{Bb}	4.46 ± 0.14^{Aa}	4.49 ± 0.17^{Aa}
Lysine	1	4.01 ± 0.64^{Ca}	6.10 ± 0.13^{Ba}	10.80 ± 0.20^{Aa}
	14	2.31 ± 0.20^{Bb}	6.22 ± 0.30^{Aa}	5.88 ± 0.72^{Ab}
	28	1.01 ± 0.01^{Cc}	4.90 ± 0.14^{Bb}	6.58 ± 0.19^{Ab}

[a] Formulations: CRC – control ricotta cream; RCLM – Ricotta cream supplemented with *Lactobacillus mucosae* CNPC007; RCLA – Ricotta cream supplemented with *Lactobacillus acidophilus* La-5. <LOD: below the limit of detection. A–C: different capital letters in the same row denote differences ($p \leq 0.05$) between the formulations at the same time during storage, according to Tukey's test or Student's t-test. a–c: different superscript letters in the same column denote differences ($p \leq 0.05$) between the same formulation at distinct storage times during storage, according to Tukey's test or Student's t-test.

two esters, one hydrocarbon, and one terpene (Table 5). 2,3-butanedione was found only in RCLM, while ethyl-decanoate was not found in this formulation. RCLM had varied amounts of volatile compounds on day 14 of storage, with a decrease in the amounts of 2-pentanone, nonanal, 1-decyne, and caryophyllene, and an increase in the amounts of 2,3-butanedione, acetic, and octanoic acid ($p \leq 0.05$).

2-nonanone, 2-heptanone, and 2-pentanone were the ketones found in higher amounts in goat ricotta cream formulations. 2-Heptanone contributes to either the herbaceous aroma (Bezerra et al., 2016) or the fresh and creamy aroma of some cheeses (Jia et al., 2021). Similarly, compound 2-nonanone is associated with the fresh and creamy aroma of semi-hard goat cheese (Jia et al., 2021). The pyruvate derivative 2,3-butanedione was identified only in RCLM, and its amounts increased during storage. 2,3-butanedione is formed from the fermentative metabolism of glucose and citric acid (Dan et al., 2017) and is associated with butter flavor (Ranadheera et al., 2019).

Two aldehydes, namely benzaldehyde and nonanal, were identified in goat ricotta cream formulations (Table 5). These compounds are important in conveying the characteristic aroma and flavor of fermented dairy products, besides helping to provide a smooth taste with malt and almond aroma notes (Dabaj, Lasekan, Manap, & Ling, 2020). The amounts of these compounds remained overall constant during storage ($p > 0.05$), except for nonanal in RCLM that reduced on day 14 of storage ($p \leq 0.05$).

Table 5
Volatile profile (AU × 10^5)[b] of goat ricotta cream formulations stored under refrigeration for 14 days. Results are expressed as an average ± standard deviation (n: 9).[a]

Class	Compounds	IR Lit	IR	Time of storage (days)	Goat ricotta cream formulations		
					CRC	RCLM	RCLA
Ketone	2,3-Butanedione	595	<800	1	nd	7.00 ± 0.48^{b}	nd
				14	nd	26.50 ± 3.60^{a}	nd
Ketone	2-Pentanone	655	<800	1	5.92 ± 2.30^{Aa}	5.90 ± 0.27^{Aa}	7.40 ± 0.07^{Aa}
				14	4.60 ± 2.50^{ABa}	1.50 ± 0.53^{Bb}	7.20 ± 0.86^{Aa}
Ketone	2-Octanone	990	994	1	0.68 ± 0.06^{Aa}	0.80 ± 0.11^{Aa}	0.67 ± 0.03^{Aa}
				14	0.91 ± 0.41^{Aa}	0.67 ± 0.14^{Aa}	1.10 ± 0.18^{Aa}
Ketone	8-Nonen-2-one	1085	1085	1	0.46 ± 0.09^{Aa}	0.69 ± 0.16^{Aa}	0.54 ± 0.08^{Ab}
				14	0.76 ± 0.35^{Aa}	0.72 ± 0.07^{Aa}	0.92 ± 0.10^{Aa}
Ketone	2-Nonanone	1092	1094	1	59.30 ± 2.48^{Aa}	83.85 ± 16.66^{Aa}	70.13 ± 9.47^{Aa}
				14	65.04 ± 18.19^{Aa}	58.64 ± 3.18^{Aa}	70.88 ± 8.42^{Aa}
Ketone	2-Undecanone	1294	1295	1	1.86 ± 0.05^{Ba}	2.60 ± 0.40^{Aa}	2.34 ± 0.10^{ABb}
				14	2.63 ± 0.88^{Aa}	2.16 ± 0.18^{Aa}	3.18 ± 0.10^{Aa}
Ketone	2-Heptanone	891	890	1	41.70 ± 1.40^{Aa}	47.00 ± 6.43^{Aa}	41.42 ± 4.61^{Aa}
				14	42.30 ± 6.84^{Aa}	38.25 ± 2.04^{Aa}	45.48 ± 8.26^{Aa}
Aldehyde	Benzaldehyde	962	962	1	2.52 ± 0.30^{Aa}	2.99 ± 0.32^{Aa}	2.87 ± 0.33^{Aa}
				14	2.50 ± 0.61^{Aa}	2.40 ± 0.48^{Aa}	3.39 ± 1.12^{Aa}
Aldehyde	Nonanal	1104	1105	1	2.36 ± 0.06^{Aa}	2.73 ± 0.30^{Aa}	2.39 ± 0.21^{Aa}
				14	2.97 ± 0.97^{Aa}	0.30 ± 0.05^{Bb}	2.53 ± 0.50^{Aa}
Acid	Acid acetic	660	<800	1	4.26 ± 0.90^{Aa}	3.90 ± 0.74^{Ab}	5.64 ± 0.40^{Aa}
				14	2.69 ± 1.60^{Ba}	12.42 ± 0.48^{Aa}	9.68 ± 4.25^{Aa}
Acid	Hexanoic acid	1001	1003	1	3.33 ± 0.65^{Aa}	3.09 ± 1.03^{Aa}	2.10 ± 0.35^{Aa}
				14	2.29 ± 1.05^{Aa}	1.64 ± 0.73^{Aa}	2.95 ± 1.41^{Aa}
Acid	Octanoic acid	1192	1191	1	14.73 ± 1.36^{Aa}	16.78 ± 4.12^{Ab}	22.34 ± 3.55^{Aa}
				14	18.74 ± 6.55^{Ba}	33.79 ± 2.51^{Aa}	22.57 ± 2.09^{Ba}
Acid	Decanoic acid	1373	1376	1	8.39 ± 1.43^{Aa}	13.84 ± 5.62^{Ab}	15.35 ± 1.34^{Aa}
				14	12.01 ± 5.99^{Aa}	19.95 ± 2.78^{Aa}	15.04 ± 0.91^{Aa}
Ester	Ethyl octanoate	1196	1199	1	1.17 ± 0.06^{Aa}	1.52 ± 0.24^{Aa}	1.44 ± 0.32^{Aa}
				14	1.53 ± 0.49^{Aa}	1.16 ± 0.68^{Aa}	1.56 ± 0.19^{Aa}
Ester	Ethyl decanoate	1396	1397	1	1.47 ± 0.04^{Ba}	Nd	1.88 ± 0.18^{Aa}
				14	1.81 ± 0.86^{Aa}	Nd	2.17 ± 0.03^{Aa}
Hydrocarbon	1-Decyne	–	1027	1	1.40 ± 0.12^{Ba}	3.34 ± 0.18^{Aa}	1.79 ± 0.53^{Bb}
				14	2.57 ± 1.84^{Aa}	0.74 ± 0.27^{Ab}	2.95 ± 0.49^{Aa}
Terpene	Caryophyllene	1419	1423	1	nd	1.17 ± 0.07^{Aa}	1.06 ± 0.05^{Ab}
				14	nd	0.80 ± 0.13^{Bb}	1.37 ± 0.13^{Aa}

[a] Formulations: CRC – control ricotta cream; RCLM – Ricotta cream supplemented with *Lactobacillus mucosae* CNPC007; RCLA – Ricotta cream supplemented with *Lactobacillus acidophilus* La-5. Nd: undetected. A–C: different capital letters in the same row denote differences ($p \leq 0.05$) between the formulations at the same time during storage, according to Tukey's test or Student's t-test. a–b: different superscript letters in the same column denote differences ($p \leq 0.05$) between the same formulation at distinct storage times during storage, according to Student's t-test.
[b] AU = arbitrary units.

Four acids were identified in goat ricotta cream formulation, where octanoic, decanoic, and acetic acids were the most predominant ($p \leq 0.05$). The amount of octanoic acid increased in RCLM on day 14 of storage ($p \leq 0.05$), and the characteristic aroma of goat cheese is attributed to this compound (Uzkuç & Yüceer, 2023). The lipolysis during cheese ripening and storage directs the increase in acid amounts, including octanoic acid (Bontinis et al., 2012). The reduced hexanoic acid amounts found in goat ricotta cream formulations (Table 5) could be important in mitigating goat aroma in these products since hexanoic acid is linked to the typical goat milk aroma (Ranadheera et al., 2019). It is important to highlight that the typical aroma of goat milk found in goat dairy products is frequently linked to a higher consumer aversion to consuming these products. Consequently, the decrease in hexanoic acid in goat ricotta cream represents an interesting and meaningful outcome for improving the sensory acceptance of this dairy product.

Acetic acid can be derived from the catabolism of lactose, citric acid, and amino acids and from propionic fermentation during cheese ripening and storage (Faccia, Trani, Natrella, & Gambacorta, 2018). RCLA and RCLM had higher amounts of acetic acid on day 14 of storage than CRC ($p \leq 0.05$). It could be linked to higher catabolism of acetic acid precursors and propionic fermentation by these microorganisms. Only two esters, namely ethyl octanoate and ethyl decanoate, were identified in goat ricotta cream formulations. Esthers are compounds highly volatile at room temperature and account for fruity and fermented aromas, which can mask unwanted odors, such as those characteristic of lipolysis (Evert-Arriagada, Hernández-Herrero, Gallardo-Chacón, Juan, & Trujillo, 2013). This feature may be important in goat dairy products since it would minimize the perception of the characteristic and more distinct goat odors linked to the presence of medium-chain fatty acids, such as capric, caprylic, and caproic acid (Costa et al., 2017).

1-decyne was the only hydrocarbon detected in the examined goat ricotta cream formulations on day 14 of storage, and its concentration increased and decreased in RCLA and RCLM, respectively ($p \leq 0.05$). Due to the high detection thresholds, hydrocarbons typically have little influence on food aroma (Bezerra et al., 2017). Generally, 1-decyne is described as having a peculiar, slightly musky aroma with subtle notes of garlic or onion, which are more prominent when this compound occurs in high amounts. However, low amounts of 1-decyne can contribute to the overall aromatic profile, adding complexity and depth to the cheese aroma (Bezerra et al., 2017).

Caryophyllene was detected only in RCLA and RCLM, indicating that supplementation of goat ricotta cream with probiotic bacteria could influence the formation of this compound. Caryophyllene is a sesquiterpene frequently detected in milk and dairy products (Bezerra et al., 2017; Sant'ana et al., 2019). It is known for providing a spicy and woody aroma, as well as for exerting important anti-inflammatory, antibacterial, anticancer, and antioxidant properties (Gonzalez-Burgos & Gomez-Serranillos, 2012).

Table 6
Results (average ± standard deviation; n: 9) of technological parameters of goat ricotta cream formulations during 28 days of refrigerated storage.[a]

Parameters		Storage time (days)	Goat ricotta formulations		
			CRC	RCLM	RCLA
Yield (g L^{-1})		1	5.31 ± 0.07^{A}	5.37 ± 0.11^{A}	5.74 ± 0.18^{A}
Color	L*	1	76.28 ± 0.24^{Bc}	73.24 ± 0.03^{Cc}	77.65 ± 0.40^{Ac}
		14	89.57 ± 0.06^{Aa}	87.34 ± 0.30^{Bb}	82.15 ± 0.02^{Cb}
		28	81.13 ± 0.61^{Cb}	88.81 ± 0.18^{Aa}	83.69 ± 0.07^{Ba}
	a*	1	-1.59 ± 0.01^{Ca}	-1.05 ± 0.02^{Aa}	-1.45 ± 0.01^{Ba}
		14	-1.92 ± 0.03^{Cb}	-1.29 ± 0.02^{Ab}	-1.54 ± 0.20^{Bb}
		28	-1.91 ± 0.08^{Cb}	-1.62 ± 0.03^{Ac}	-1.75 ± 0.03^{Bc}
	b*	1	6.44 ± 0.02^{Bb}	6.54 ± 0.02^{Ac}	5.37 ± 0.01^{Cb}
		14	6.68 ± 0.01^{Ba}	7.85 ± 0.05^{Ab}	6.45 ± 0.09^{Ba}
		28	6.83 ± 0.11^{Ba}	8.62 ± 0.06^{Aa}	6.47 ± 0.06^{Ba}
Hardness (N)		1	1.17 ± 0.03^{Ba}	1.22 ± 0.03^{Ba}	1.66 ± 0.13^{Aa}
		14	0.84 ± 0.08^{Bb}	0.82 ± 0.10^{Bb}	1.44 ± 0.12^{Aa}
		28	0.71 ± 0.05^{Ab}	0.79 ± 0.09^{Ab}	0.72 ± 0.06^{Ab}
Adhesiveness (g s^{-1})		1	-885.59 ± 9.01^{Ab}	-869.12 ± 6.51^{Ab}	-1157.58 ± 10.11^{Bc}
		14	-467.01 ± 50.96^{Aa}	-473.17 ± 34.44^{Aa}	-1034.32 ± 18.41^{Bb}
		28	-419.31 ± 16.70^{Aa}	-533.70 ± 35.84^{Ba}	-421.00 ± 13.32^{Aa}
Springiness		1	0.95 ± 0.01^{Aa}	0.95 ± 0.01^{Aa}	0.96 ± 0.01^{Aa}
		14	0.95 ± 0.01^{Aa}	0.95 ± 0.01^{Aa}	0.95 ± 0.01^{Aa}
		28	0.95 ± 0.01^{Aa}	0.96 ± 0.01^{Aa}	0.96 ± 0.01^{Aa}
Cohesiveness		1	0.79 ± 0.01^{Aa}	0.83 ± 0.08^{Aa}	0.80 ± 0.01^{Aa}
		14	0.79 ± 0.01^{Aa}	0.81 ± 0.02^{Aa}	0.78 ± 0.02^{Aa}
		28	0.79 ± 0.01^{Aa}	0.79 ± 0.11^{Aa}	0.77 ± 0.04^{Aa}
Chewiness		1	0.92 ± 0.03^{Ba}	1.01 ± 0.03^{Ba}	1.32 ± 0.10^{Aa}
		14	0.66 ± 0.05^{Bb}	0.66 ± 0.09^{Bb}	1.12 ± 0.08^{Aa}
		28	0.56 ± 0.05^{Ab}	0.62 ± 0.07^{Ab}	0.55 ± 0.04^{Ab}
Gumminess (N)		1	0.87 ± 0.03^{Ba}	0.96 ± 0.03^{Ba}	1.27 ± 0.11^{Aa}
		14	0.62 ± 0.05^{Bb}	0.63 ± 0.08^{Bb}	1.08 ± 0.09^{Aa}
		28	0.53 ± 0.05^{Ab}	0.59 ± 0.07^{Ab}	0.53 ± 0.04^{Ab}

[a] Goat ricotta cream formulations: CRC – control ricotta cream; RCLM – Ricotta cream supplemented with *L. mucosae* CNPC007; RCLA – Ricotta cream supplemented with *L. acidophilus* La-5. A–C: different capital letters in the same row denote differences ($p \leq 0.05$) between distinct formulations at the same storage time, according to Tukey's test. a–c: different superscript letters in the same column denote differences ($p \leq 0.05$) between the distinct storage times for the same formulation, according to Tukey's test.

Interestingly, 2,3-butanedione was detected only in RCLM (Table 5). 2,3-butanedione (diacetyl) is typically associated with the buttery flavor in fermented dairy products (Cui et al., 2019). Additionally, RCLM had the highest amounts of octanoic on day 14 of storage. This volatile compound is linked to the characteristic odor of fermented milk, impacting positively the flavor of dairy products (Dan et al., 2017). These results suggest that the supplementation of goat ricotta cream with *L. mucosae* CNPC007 contributed to the differentiation of this product, which could contribute to enhancing the acceptability of sensory parameters, such as aroma.

3.5. Techno-functional characteristics of goat ricotta cream

The supplementation with tested probiotic strains did not affect the yield of goat ricotta cream ($p > 0.05$), which ranged from 5.31 to 5.74 g 100 g^{-1} (Table 6). Yield is a important parameter for industrial-scale production and profitability (Lopes et al., 2021). The yield values detected in this study were higher than those previously reported for goat ricotta cheese supplemented with *L. acidophilus* La-5 and *Bifidobacterium lactis* Bb-12 (4.26–4.51 g L^{-1}) (Meira et al., 2015), but were lower than those reported for goat ricotta cheese supplemented with microencapsulated *L. acidophilus* La-5 (6.65–7.44 g L^{-1}) (Lopes et al., 2021). In ricotta manufacturing, factors, such as milk composition (protein and fat concentration), coagulant choice (e.g., lactic or citric acid), salt content, enrichment ingredient addition (whole milk or cream), and heat treatment (heating mode and whey heating speed) can influence the final yield (Mangione, Caccamo, Natalello, & Licitra, 2023).

Regarding the color analyses, the examined goat ricotta cream formulations had a higher luminosity (L*) with a yellowish-green hue. L* values ranged between 73.24 and 89.57, a* values ranged between −1.05 and −1.92, and b* values ranged between 5.37 and 8.62. The high luminosity values (L*) in goat ricotta cream could be linked to the protein matrix of this product (Sameer, Ganguly, Khetra, & Sabikhi, 2020). Goat cheeses typically have higher luminosity than cow cheese due to the smaller size of goat milk fat globules (Borba et al., 2014) and the higher capability of goats to convert beta-carotene into vitamin A (Lucas, Rock, Agabriel, Chilliard, & Coulon, 2008).

The low a* values indicated a tendency toward a green color in all examined goat ricotta cream formulations. CRC had a more pronounced green hue compared to RCLM and RCLA ($p \leq 0.05$), which could be linked to the presence of riboflavin accounting for the greenish color of whey used to produce ricotta (Mestdagh, Kerkaert, Cucu, & Meulenaer, 2011). The green chromaticity (a*) decreased during storage in the examined goat ricotta cream formulations ($p \leq 0.05$), probably due to riboflavin oxidation over time.

The b* values increased in all samples during storage and were always higher in RCLM ($p \leq 0.05$) than in CRC and RCLA. This parameter is related to the color spectrum varying from blue (−b*) to yellow (+b*), which was influenced by storage time and goat ricotta cream formulation. Various factors contribute to color change during the processing and storage of dairy products, including heat/pasteurization, handling, and interaction between formed metabolites and added ingredients (Prudencio, Müller, Fritzen-Freire, Amboni, & Petrus, 2014). For example, pasteurization during ricotta production can favor Maillard reactions, influencing the product color and causing yellowing (Dattatreya & Rankin, 2006).

Furthermore, different probiotic bacteria can influence cheese color, especially during storage, since these microorganisms produce metabolites that interact with cheese components and are involved in enzymatic reactions modifying cheese components, leading to color changes; by interacting with other microorganisms present in cheese through competition or metabolic cooperation, affecting indirectly the cheese color; and produce natural pigments, impacting directly the cheese color (Anihouvi & Kesenkaş, 2023; Mayo, Rodríguez, Vázquez, & Flórez, 2021). In this study, *L. mucosae* CNPC007 had a much greater influence on intensifying the yellow color of ricotta cream during storage compared to the cheeses supplemented with *L. acidophilus* La-5 or without probiotic bacteria supplementation.

The hardness (firmness) is related to the force required for sample pre-deformation. The hardness values were low in the examined goat ricotta cream formulations and ranged between 0.71 and 1.66 N. These low hardness values could be expected since ricotta cream is a soft and creamy consistency product. The hardness, chewiness, and gumminess values decreased in the examined goat ricotta cream formulations during storage ($p \leq 0.05$). RCLM and CRC had higher acidity and lower firmness, chewiness, and gumminess than RCLA until at least day 14 of storage ($p \leq 0.05$). The action of residual coagulant and the activity of microbial enzymes (Silva, Silva, Garcia, & Santos, 2019), along with the usual increase in acidity during cheese fermentation and storage, may compromise the cheese protein matrix, leading to reduced hardness, chewiness, and gumminess (Buriti, Rocha, & Saad, 2005; Moraes et al., 2018).

The goat ricotta cream became less adhesive during storage ($p \leq 0.05$), with values ranging between −1157.58 and −419.31 g s^{-1}, which could be related to increased exopolysaccharide production by lactic acid bacteria in the ricotta cream at the beginning of storage (Bomfim et al., 2020). Goat ricotta cream formulations had overall low springiness (0.95–0.96), with no clear influence of *L. mucosae* CNPC007 or *L. acidophilus* La-05 supplementation and storage time on this parameter ($p > 0.05$). Likewise, *L. acidophilus* La-05 or *L. mucosae* CNPC007 supplementation did not impact the cohesiveness of goat ricotta cream during storage ($p > 0.05$).

3.6. Microbiological parameters of goat ricotta cream

The results of the hygienic-sanitary microbiological analysis showed the examined goat ricotta cream formulations as suitable for human consumption during the measured storage period since the counts of coagulase-positive *Staphylococcus* and *E. coli* were below 2 log CFU g^{-1}, and *Salmonella* spp. was not detected.

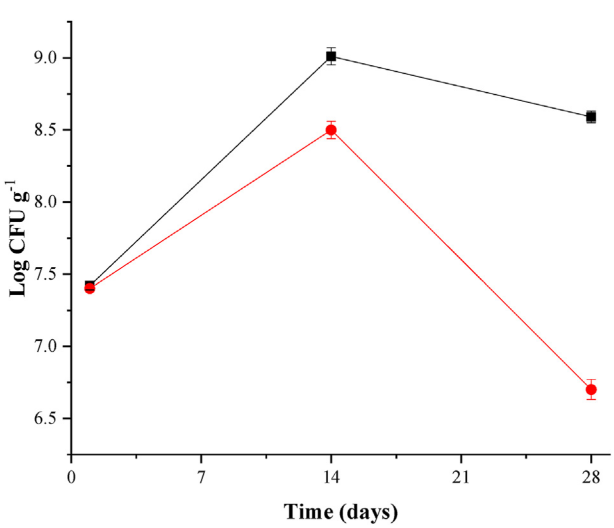

Fig. 3. Viable cell counts of *L. mucosae* CNPC007 (■) and *L. acidophilus* La-5 (●) in goat ricotta cream formulations during 28 days of refrigerated storage.

Table 7
Results (average ± standard deviation; n: 9) of sensory acceptance of goat ricotta cream formulations at day 7 of refrigerated storage.[a]

Sensory attributes	Goat ricotta cream formulations		
	CRC	RCLM	RCLA
Appearance	8.30 ± 0.56[A]	8.53 ± 0.60[A]	8.37 ± 0.69[A]
Color	8.55 ± 0.54[A]	8.48 ± 0.52[A]	8.48 ± 0.60[A]
Texture	8.40 ± 0.76[A]	8.17 ± 0.69[A]	8.05 ± 0.96[A]
Aroma	8.30 ± 0.93[A]	8.01 ± 0.67[A]	8.06 ± 0.76[A]
Taste	8.38 ± 0.88[A]	8.22 ± 0.80[AB]	7.85 ± 1.18[B]
Global acceptance	8.30 ± 0.65[A]	8.08 ± 0.65[A]	7.98 ± 0.94[A]
Purchase intention	4.45 ± 0.68[A]	4.35 ± 0.66[A]	4.28 ± 0.70[A]

[a] Formulations: CRC – control ricotta cream; RCLM – Ricotta cream supplemented with *Lactobacillus mucosae* CNPC007; RCLA – Ricotta cream supplemented with *Lactobacillus acidophilus* La-5. A–B: different capital letters in the same row denote differences ($p \leq 0.05$) between the formulations, according to Tukey's test.

Viable cell counts of *L. mucosae* CNPC007 and *L. acidophilus* La-05 remained above 6 log CFU g^{-1} during the measured storage period (Fig. 3) and higher than the commonly reported minimum dose of probiotics for supplemented products to confer health benefits to consumers (Terpou et al., 2019). The increase in viable cell counts of *L. mucosae* CNPC007 and *L. acidophilus* La-05 in goat ricotta cream formulations up to 14 days of storage could be linked to an increased bacterial metabolic activity and favorable pH and acidity conditions in these products. RCLM had the highest count of viable probiotic cells (i.e., 8.56 log CFU g^{-1}) at the end of the measured storage period, accompanied by a higher acidity and lower pH than RCLA and CRC (Table 1). These results underscore the significant influence of *L. mucosae* CNPC007 proliferation on the fermentative parameters of examined goat ricotta cream formulations, as well as a greater tolerance of this strain to the more acidic pH found in these matrices.

The increase in the counts of probiotics during storage could have contributed to the increase in depth of proteolysis in RCLM and RCLA, with a concomitant increase in the concentration of essential and non-essential amino acids, affecting positively the nutritional value and potential bioactivity of these formulations. The release of essential amino acids during storage can impact the increase in the nutritional value of ricotta cream, providing a more bioavailable source of these nutrients for absorption in the intestinal tract and contributing to additional health benefits.

3.7. Sensory analysis of goat ricotta cream

All examined goat ricotta cream formulations were well accepted regarding the sensory attributes evaluated using a 9-point hedonic scale (Table 7), with scores higher than 5, corresponding to the hedonic term “neither liked/neither disliked”. The goat ricotta cream formulations did not differ ($p > 0.05$) in appearance, color, texture, aroma, global acceptance, and purchase intention. RCLA scored lower for taste than CRC ($p \leq 0.05$), whereas RCLM did not differ from CRC ($p > 0.05$). The hedonic term for RCLA and RCLM taste ranged from “liked moderately” to “liked very much”. The supplementation of *L. acidophilus* La-05 and *L. mucosae* CNPC007 did not affect negatively the sensory acceptance or purchase intention of goat ricotta cream.

According to the general preference ranking test (data not shown), RCLA and RCLM were equally preferred ($p > 0.05$), whereas CRC was less preferred than RCLA and RCLM ($p \leq 0.05$). Regarding JAR or Ideal Scaling test, any attribute that 70% or more of the panelists consider ideal strongly influences global acceptance (Fig. 4). The color, consistency, and texture had the greatest impact

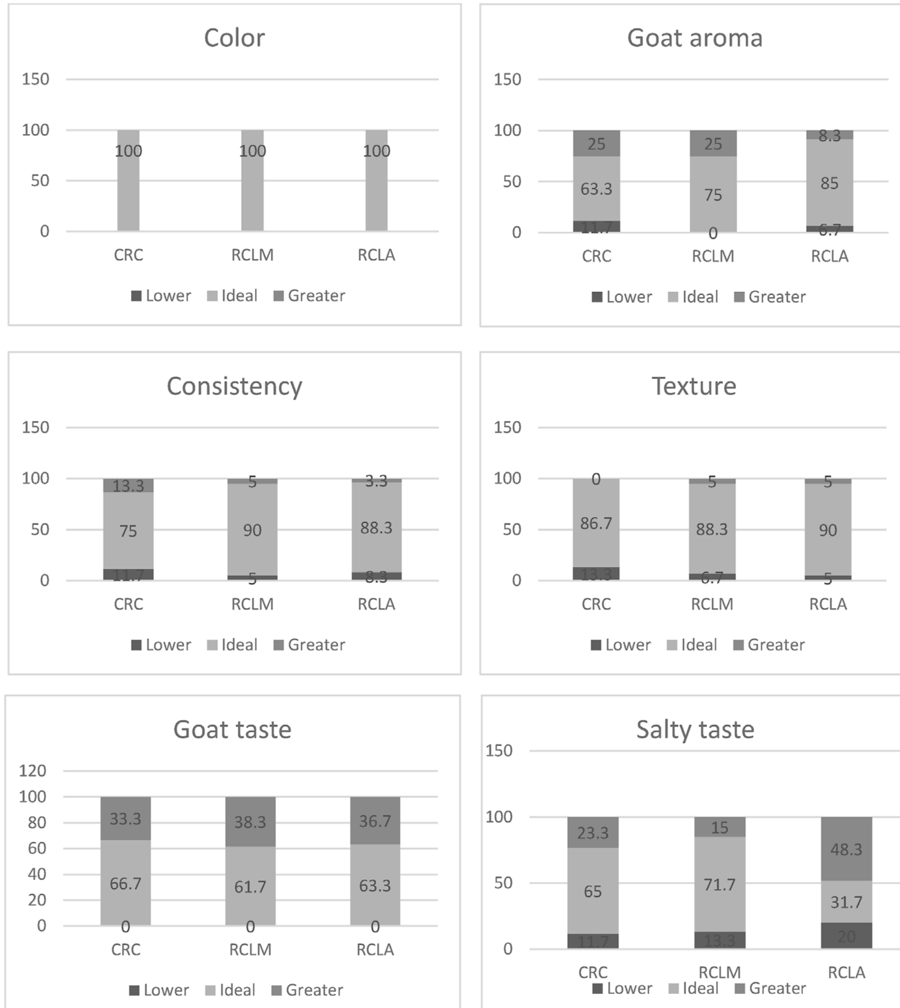

Fig. 4. Comparison of JAR results for different attributes between goat ricotta cream formulations.

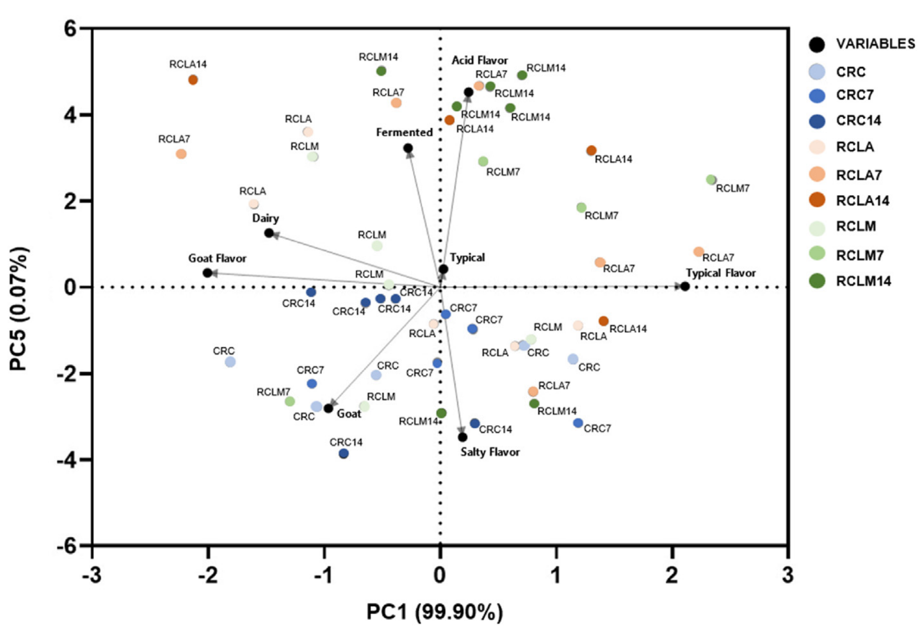

Fig. 5. Principal component analysis (PCA) of the correlation between the perception of specific characteristics of goat ricotta cream formulations (n = 3) on days 1, 7, and 14 of refrigerated storage. Formulations: CRC – Control ricotta cream; RCLM – Ricotta cream supplemented with *L. mucosae* CNPC007; RCLA – Ricotta cream supplemented with *L. acidophilus* La-5.

on the global impression of goat ricotta cream formulations. RCLM was considered by 71.7% of the panelists as ideal regarding saltiness (salty taste), followed by CRC (65% of the panelists) and RCLA (31.7% of panelists).

Using the ideal scale for the goat flavor attributes, no formulation had a negative impact on sensory evaluations. RCLA and RCLM were identified as ideal regarding goat aroma. However, no difference ($p > 0.05$) for aroma was observed when the formulations were evaluated in sensory acceptance testing (Table 7).

Four aroma attributes (fermented, goat, typical, and dairy) and four flavor attributes (acid, salty, goat, and typical) were defined and considered important for consumers in the PAE method. The correlation between aroma and flavor attributes was analyzed on days 1, 7, and 14 of storage (Fig. 5), where PC1 and PC2 explained 99.9% and 0.07%, respectively. According to the PCA map, RCLM and RCLA were identified mostly on days 7 and 14 of storage as the samples with the most outstanding acidic and fermented aroma and characteristic product flavor. These results agree with the volatile profile, where RCLM and RCLA had the highest acid concentration, especially at the end of the measured storage period. CRC was most strongly associated with goat flavor and aroma on different storage periods (1, 7, and 14 days), indicating that *L. acidophilus* La-05 or *L. mucosae* CNPC007 supplementation minimized the perception of these attributes.

CRC and RCLM were identified with a salty taste from day 7 to 14 day of storage. However, the perception of a saltier taste did not negatively impact the sensory evaluation of these formulations (Fig. 5). According to the JAR test results, RCLM and CRC were considered ideal in terms of saltiness by 71.7% and 65% of the panelists, respectively (Fig. 4).

4. Conclusions

This study demonstrated that supplementing goat ricotta cream with *L. mucosae* CNPC007 either improves or does not negatively impact its physicochemical properties, volatile compound profile, techno-functional, and sensory attributes. Goat ricotta cream supplemented with *L. mucosae* CNPC007 exhibited increased luminosity with a yellowish-green hue, besides having the lowest adhesiveness on day 28 of refrigerated storage. The fermentation process mediated by *L. mucosae* CNPC007 led to increased lactose degradation and higher lactic acid production during storage, which was probably influenced by *L. mucosae* CNPC007 multiplication over time, reaching viable cell counts >8.5 log CFU g^{-1} on day 28 of refrigerated storage. *L. mucosae* CNPC007 influenced the volatilomic profile, promoting the emergence of compounds responsible for characteristic flavors in fermented dairy products. *L. mucosae* CNPC007 supplementation did not impact the overall acceptance or purchase intention of goat ricotta cream but affected positively the preference and ideal goat aroma. These results contribute to promoting the use of the autochthonous *L. mucosae* CNPC007 strain in goat ricotta cream and favor the development of novel functional products for the food industry with improved technological, nutritional, bioactive, and sensory characteristics.

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Data availability

Data could be made available on request.

CRediT authorship contribution statement

Márcia Gabrielle Silva Viana: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Daniela Karla Medeiros Vasconcelos:** Methodology, Formal analysis. **Maria Isabel Ferreira Campos:** Methodology, Formal analysis. **Leila Moreira de Carvalho:** Methodology, Formal analysis. **Lary Souza Olegário:** Methodology, Formal analysis. **Mércia de Sousa Galvão:** Methodology, Formal analysis. **Karina Maria Olbrich dos Santos:** Resources, Methodology, Formal analysis. **Antônio Silvio do Egito:** Resources, Methodology, Funding acquisition, Formal analysis. **Marta Suely Madruga:** Supervision, Methodology, Formal analysis. **Marcos dos Santos Lima:** Methodology, Formal analysis. **Tatiane Santi Gadelha:** Supervision, Methodology, Formal analysis. **Maria Teresa Bertoldo Pacheco:** Supervision, Methodology, Formal analysis. **Viviane Priscila Barros de Medeiros:** Writing – review & editing. **Evandro Leite de Souza:** Writing – review & editing, Formal analysis. **Maria Elieidy Gomes de Oliveira:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Data curation, Conceptualization.

Declaration of competing interest

The authors declare no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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