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Physicochemical profile of milk and cheese of goat feed with flashseed oil substituting the corn

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Abstract

The objective of this research was to evaluate the physicochemical quality of milk and cheese from goats-fed diets containing different concentrations of flaxseed oil in replacement of corn. Eight multiparous Saanen goats weighing 51.0 ± 8.0 kg and 67.0 ± 18.0 days of lactation were used. According to the concentrations of linseed oil inclusion in the diet, the goats were randomly distributed in a latin square (4 x 4), according to the concentrations of linseed oil inclusion in the diet (0, 1, 2, and 3%). Milk samples from each animal were collected twice a day, at regular times, during the three days of data collection in each period, for subsequent physicochemical and fatty acid profile analysis employing gas chromatography. The non-fat solids (P = 0.0302) and density (P = 0.0327) variables sgnificantly affected linseed oil in the goats' feed. Regressive effects (linear and quadratic) were not observed for other variables studied, except for lactose and density. Thus, 20 fatty acids have been identified in goat milk, which gives us an essential source of information about animal diet and milk quality concerning human health benefits. Furthermore, there were changes in the lipid profile of milk, decreasing saturated fatty acids and increasing unsaturated fatty acids, resulting in health-promoting effects.

Keywords: economic analysis; fatty acids; instrumental color; saturated; unsaturated.

Practical Application: The modification of nutrition aspects of dairy goats is important because it can allow milk and dairy products with even better nutritional and functional characteristics. The improvement of goat milk through the ingestion of polyunsaturated fatty acids, with flaxseed (Linum usitatissimum. L.) being an alternative food source for ruminants, as it is a source of omega-3 and omega-6, these fatty acids being beneficial to human health, especially for cardiovascular diseases.

1 Introduction

Goats have been domesticated animals for many years, providing milk and dairy products for the livelihood of humans and a healthy and nutritious diet (Park et al., 2007). Goat's milk plays an essential role in the health and nutrition of consumers in different countries; it is nutritionally vital in the population's diet (Ribeiro & Ribeiro, 2010). Consumers are interested in nutritional composition, microbiological quality, and foods that, in addition to nourishing, can bring other health benefits. Interest in the consumption of goat milk and its derivatives has been increasing, following the trend towards the consumption of healthier foods (Linares et al., 2017)

Goat's milk is a food with an essential nutritional composition (protein, fat, calcium, phosphorus, and vitamins), in addition to being a source of components capable of reducing the onset of diseases, that is, with functional potential, which, in addition to nourishing, provides an effect beneficial to health (Fonteles et al., 2016). Goat milk contains a high level of short-and medium-chain fatty acids with a small size of fat globules (~2.5–3 μm in diameter), while it has a low level of αs1-casein (4.5%–34% of the total protein) and a high level of β-casein (34%–64% of the total protein) (Günay et al., 2021). Moreover, goat milk also has whey proteins (WPs) at a level of 3–12 g/kg. WPs consist of β-lactoglobulin (34%–47% of the total WPs), α-lactalbumin (17%–50% of the total WPs) and serum albumin (5%–22% of the total WPs) (Alichanidis et al., 2016). The natural and healthy image and specific taste of goat milk make goat dairy products a profitable alternative (Fangmeier et al., 2019). This is because goat's milk is known for its beneficial and therapeutic effects on people who are allergic to cow's milk which, combined with nutritional and health benefits, strengthen the potential and value of goat milk and its derivatives (Günay et al., 2021; El-Shafei et al., 2020; Hadjimbei et al., 2020; Popovic-Vranjes et al., 2017)

Thus, in addition to properly nourishing dairy goats, modifying some aspects of animal nutrition can allow milk and dairy products with even better nutritional and functional characteristics (Fonteles et al., 2016). Researches have been related to improving

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goat milk through the ingestion of polyunsaturated fatty acids (PUFA). Flaxseed (Linum usitatissimum. L.) is an alternative food source for ruminants, considering that it is a source of omega-3 and omega-6, and these fatty acids are beneficial for human health, especially for cardiovascular diseases (Onetti et al., 2001; Abuelfatah et al., 2016), being pointed out as a bioactive compound of functional foods (Ribeiro & Ribeiro, 2010). Cheeses are generally nutrient-dense foods and are a valuable source of high-quality proteins, lipids, vitamins (e.g. vitamin A, B2 and B12) and minerals (particularly calcium and phosphor (Feeney et al., 2021). The cheese also contains relatively high levels of saturated fatty acids (SFAs), which are commonly perceived as negatively impacting the healthfulness of the diet, and have been associated with increased blood LDL-cholesterol levels, often considered a marker for cardiovascular disease (CVD) risk (Ference et al., 2019).

Flaxseed oil has polyunsaturated fatty acids and can be an alternative source for feeding lactating goats. Studies carried out by Caroprese et al. (2016), using whole flaxseed, verified quantitatively and qualitatively positive effects on goat milk. However, data regarding the supplementation of dairy goats with flaxseed oil are scarce in the literature. Therefore, studies are needed to identify its effects on animal nutrition and improve milk and its products. Thus, this study aimed to evaluate milk and rennet cheese's physicochemical characteristics and the fatty acid profile of goat milk -fed with diets with different concentrations of flaxseed oil as a substitute for corn.

2 Material and methods

2.1 Experiment site

The experiment was carried out at the Laboratory of Goats and Sheep Culture of the Center for Human, Social, and Agrarian Sciences belonging to the Federal University of Paraíba, located in the municipality of Bananeiras, State of Paraíba, micro-region of Brejo Paraibano. The local altitude is 552 m, lying between the geographic coordinates 6°41'11" south latitude and 35°37'41" longitude, west of Greenwich, with a hot and humid climate. The region's temperature varies between a maximum of 36 °C and a minimum of 18 °C, with an average annual rainfall of 1200 mm.

2.2 Animal and diet

The project was submitted to the animal research ethics council and received protocol number 7586020519. Eight multiparous Saanen goats weighing 51±8 kg and 67±18 days of lactation were used. The animals were kept in a confinement system for 60 days. They were housed in a covered shed and kept in individual stalls made of wood, equipped with a feeder and drinking fountains.

According to the concentrations of linseed oil inclusion in the diet, the goats were randomly distributed in a latin square (4x4). The linseed oil, cold-pressed, for characterization and inclusion in experimental diets, was purchased from the company A. Azevedo Indústria e Comércio de Óleos Ltda., located in São Paulo-SP. The ingredients used in the animals' diets were ground corn bran, soybean bran, wheat bran, vitamin/mineral supplement, Tifton hay, and flaxseed oil concentrations (0, 1, 2, and 3%), as described in Table 1. Diets were adjusted to meet the needs recommended by the National Research Council (2007), for lactating goats with a production of 2.0 kg of milk/day and 4% fat, with a roughage: concentrate ratio of 55:45.

The lipid profile of flaxseed oil used in the diet is described in Table 2.

Table 1. Percentage and bromatological composition of experimental diets.

Ingredient (g kg^{-1} DM)	Level of inclusion (%)			
	0.0	1.0	2.0	3.0
Ground corn	335	325	315	305
Wheat bran	50	50	50	50
Soybean meal	95	95	95	95
Tfton hay	500	500	500	500
Linseed oil	0.00	10.0	20.0	30.0
Calciticlimestone	5.0	5.0	5.0	5.0
Mineral supplement[1]	15.0	15.0	15.0	15.0
Chemical composition				
Dry matter, DM (g kg^{-1} as fed)	952	952	952	952
Crude protein. (g kg^{-1} DM)	126	126	125	124
Ethereal extract. (g kg^{-1} DM)	252	254	256	257
Neutral detergent fiber. (g kg^{-1} DM)	513	511	508	506
Fiber in acid detergent. (g kg^{-1} DM)	254	253	252	251
Calcium (g kg^{-1} DM)	6,41	6,42	6,43	6,44
Phospphor (g kg^{-1} DM)	3,83	3,83	3,84	3,84
Total carbohydrates (g kg^{-1} DM)	782	774	765	756
Non-fibrous carbohydrates (g kg^{-1} DM)	297	291	285	278
Metabolizable energy. ME (Mcal kg^{-1} DM)	2.47	2.52	2.57	2.61

[1]Composition of mineral supplement per kg: P: 70 g; Ca: 140 g; Na: 148 g; S: 12 g; Mg: 1.320 mg; F: 700 mg; Zn: 4.700 mg; Mn: 3.690 mg; Fe: 2.200 mg; Co: 140 mg; I: 61 mg; Se: 15 mg; Monensinasódica: 100 mg.

Table 2. Lipid profile (%) of flaxseed oil used in experimental diets.

Lipid profile (%)	Linseed oil
C13: 0	0.05
C14: 0	0.04
C16: 0	4.86
C17: 0	0.03
C18: 0	3.09
C20: 0	0.11
C22: 0	0.23
C24: 0	9.91
C16: 1	0.07
C17: 1	0.02
C18: 1n9	19.55
C20: 1n9	0.13
C24: 1n9	0.14
C18: 2n6	12.78
C18: 3n3	48.52
C20: 2	0.09
C20: 4n6	0.23
C20: 5n3	0.08
C22: 6n3	0.06
∑ Saturated	18.32
∑ Unsaturated	81.67
∑ Monounsaturated	19.91
∑ Polyunsaturated	61.76

2.3 Experimental management

Before the beginning of the experiment, the animals were dewormed, identified, and randomly distributed in individual pens. Then, the diets were offered ad libitum at 7:30 a.m. and 4:30 p.m., as a complete mixture, in two meals a day, right after milking.

The animals went through four periods of 15 days, with the last three days for data collection. During the adaptation and collection periods, daily weighing of food supply and leftovers was carried out to calculate voluntary consumption and adjust the food offered to guarantee 10% leftovers based on dry matter. In addition, water was provided ad libitum, and consumption was quantified daily during the data collection period.

2.4 Physicochemical analysis of milk

Throughout the experiment, milking was performed manually, occurring twice a day at the times of (6:00 a.m. and 3:00 p.m.), including adaptation periods and data collection, and the dairy control was performed by weighing. Milk (kg/day) during the three days of collection of each period (all experimental period). Before milking, the goats' udders were washed with chlorinated water, dried with paper towels, and then tested for mastitis (black bottom mug test). After each milking was done post-dipping, the goats' roofs were dipped in a 2% iodine solution.

Milk samples from each animal were collected twice a day, at regular times, during the three days of each period's data collection, respecting the proportion of milk milked (morning/afternoon). First, vials and glassware were sanitized at 105 °C for one h to avoid contamination by milk residues from the previous milking. Then, the samples of the morning production were conditioned in a refrigerated environment (4 °C) to be later mixed to the milk samples of the afternoon, forming a sample composed of goat per day. From the whole milk milked per animal (kg day^{-1}), an aliquot of 200 mL was taken (with the participation of the samples proportional to the morning and afternoon milking) to analyze the physicochemical characteristics. After being placed in identified plastic bottles, the samples were slowly pasteurized at 65 °C for 30 minutes (Brasil, 2001) and finally frozen at -4 °C (in a freezer) for further analysis.

Physicochemical requirements for fat (%), non-fat solids (%), protein (%), lactose (%), moisture (%), ash (%), relative density at 15/15 °C (g mL-1), cryoscopic index (°C), acidity and pH were evaluated according to the Master Complete® Milk Analyzer (AKSO®, São Leopoldo, Rio Grande do Sul, Brasil), under specific technical conditions.

2.5 Fatty acid profile

The samples were homogenized with glass sticks, and 100 mL aliquots of milk were removed and subjected to centrifugation for 5 minutes to separate the fat 2 g aliquots were obtained from these samples for the extraction, saponification, and esterification processes (Folch et al., 1957). Next, we added 4.4 ml of the 1.5% NaCl solution to the filtrate and centrifuged at 2400 rpm for 20 minutes to separate the phases. After centrifugation, the nonpolar phase, where fatty acids are suspended, was transferred to tubes with a lid. These tubes were placed in a water bath at 50 °C and inflated with nitrogen gas until the solvent had evaporated entirely.

After obtaining the lipid fraction, esterification was performed as recommended by Kramer et al. (1997). After that, 3.0 mL of the 10% methanolic HCL solution was added and vortexed for 1 minute. Then the tubes were again taken to the water bath at 80 °C for 10 minutes, removed and, after reaching room temperature, 1 mL of hexane and 10 mL of the 6% potassium carbonate solution were added, vortexed, and subsequently centrifuged at 1,500 rpm for 5 minutes to collect the supernatant. Finally, the samples were injected in a gas chromatograph (model GC-2010 Plus Shimadzu®) with a fused silica capillary column (SP-2560; 100 m, 0,25 mm e 0,2 µm layer thickness, Supelco®).

Stearic acid (C18:0) was used as an external standard and nonadecanoic acid (C19:0) as an internal standard to detect possible losses of fatty acids during the esterification process. The fatty acids results were quantified by normalizing methyl esters' areas and expressed as a percentage of area. From the fatty acid composition data, the total saturated fatty acids (SFA), monounsaturated (MUFA), polyunsaturated (PUFA) and the relationships between MUFA and SFA, PUFA and SFA, unsaturated fatty acids (UFA), and SFA were calculated in addition to omega-6 (n-6) and omega-3 (n-3) fatty acids.

2.6 Economic analysis of milk

The economic analysis consisted of milk production and the cost of food. Facilities and labor costs vary depending on the characteristics of each production system and would be "fixed" for similar systems that adopt the same handling conditions.

The ingredients were quoted in may 2020 to calculate the diet cost, considering the average price adopted in the region. Thus, the final cost per kg of diets was R$ 1.28; 1.34; 1.40, and 1.47, at levels of 0, 1, 2, and 3% replacement of corn by linseed oil, respectively. The economic analysis considered the cost of milk at R$ 2.50/l L, so the economic analysis only reflects the cost of food.

2.7 Cheesemaking

The rennet-type cheeses were elaborated according to the cheesemakers' technique that integrates the milk and Derivatives sector, coming from Campus III, Bananeiras-PB. First, the milk from each treatment (0, 1, 2, and 3%) was pasteurized and used to make the cheeses.

After the milk arrived at the Dairy Research and Development Laboratory, this milk was filtered through a 120 mesh nylon filter, avoiding any physical contaminants present in the milk. For the pasteurization process, a temperature of 65 ºC for 30 minutes was used. Next, the milk was cooled in a stainless steel tank, placing the pan over the water, stirring it until it reached the ideal temperature of 36 ºC, to place the rennet.

Lactic yeast (Streptococcus lactis and Streptococcus cremoris) were added to the milk in natura in the proportion of 10 mL for each 10 L of milk and calcium chloride (5 mL for each 10 L) and 30 g of sodium chloride. Next, liquid rennet was added, adding 10 mL for every 10 L of milk, measured at the temperature of the process, at approximately 36 ºC, where coagulation occurs in 30 minutes. After the coagulation period had passed, the dough was cut using lyres, vertically (two directions) and horizontally (one way), to standardize the size of the curd grains. Thus, the beans were effectively homogenized, avoiding wasting dough. After homogenization, the dough was placed to rest for about 5 minutes; then, it was heated under stirring at a temperature of 41°C, making it consistent and firm. After heating, the mass was allowed to cool down to 36 ºC for further drying to obtain greater cheese firmness. The desorption process consisted of removing whey from the mass, carried out with the aid of a beaker, placing the mass in polypropylene molds. Finally, the weighing process was carried out on a semi-analytical scale.

For the molding, plastic molds made of polypropylene (with desorator) were used. For pressing, a manual press with weights of 5 kg was used. The cheeses were packed in high-density polyethylene plastic bags, with vacuum closing with a sealer. The cheeses spent a two-day storage period in refrigeration at 10 ºC to acquire a pleasant sensory quality (maturation or ripening). After that, they were refrigerated at a temperature of 10 ºC in the Laboratory for Research and Development in Dairy Products.

At the end of the cheese processing, they were kept in a suitable container, being relocated in the cold chamber located in the same cheese processing laboratory. These, in turn, underwent the maturation process for three (3) days, at a temperature of 10 ºC (± 1.0 ºC), as recommended by the Technical Regulation of Identity and Quality of Coalho Cheese (Brasil, 2000).

2.8 Physicochemical analysis of cheese

The physicochemical analyzes were carried out at the Laboratory of Physical Chemistry of Food at UFPB, Campus III – Bananeiras-PB. The water activity (aw) was determined by the measuring device, model AQUA LAB 4TE, brand DECAGON DEVICES (BR). The pH is measured with the aid of a PHmeter, model Tec-2, brand TECNAL (BR). The titration process observed total Titratable Acidity with 0.1 M sodium hydroxide until light pink.

Moisture analysis was determined by direct heating in an oven at 105 ºC, according to protocol 925.09 (Association of Analytical Chemists, 2010). The gravimetric method determined the percentage of ash based on the organic matter loss, submitted to incineration in a muffle at 550 ºC – method 923.03 (Association of Analytical Chemists, 2010). Protein was determined by the Micro-Kjeldahl method, using a correction factor of 6.38 – method 991.23 (Association of Analytical Chemists, 2010). The methodology described by Folch et al. (1957) – method 920.39 (Association of Analytical Chemists, 2010) to determine ether extract.

The fat in the dry extract (GES) was obtained through the ratio of the lipid content by the total dry extract, multiplying the value obtained by 100 (Instituto Adolfo Lutz, 2008). The total dry extract (TDE) was obtained by subtracting the major cheese parameters by the water content (TDE = 100 – Moisture) (Instituto Adolfo Lutz, 2008).

The determination of the instrumental color was carried out in a Minolta colorimeter, model CR-300, using the CIELAB system. In the CIELAB colorimetric space, defined by L*, a*, b*, where the L* coordinate corresponds to the luminosity, a* and b* refer to the green (-) / red (+) and blue (-) chromaticity coordinates/yellow (+), respectively.

2.9 Statistical analysis

In a rotating experiment, the trial was performed in triple 4x4 Latin square design, with 4 treatments and 4 periods. The milk and cheese quality was analyzed in a completely randomized design with four treatments (four kinds of cheese from the four diets offered to the animals). To verify the difference between treatments, an analysis of variance (ANOVA) was performed, and then the Tukey test was applied at the level of 5% probability using the SAS Institute (2001).

3 Results and discussion

The non-fat solids (P = 0.0302) and density (P = 0.0327) variables showed a significant effect with the inclusion of linseed oil in the goats' feed (Table 3).

The fatty solids increased their concentration with the inclusion of linseed oil, the control group being the one with the lowest value and being statistically similar to the treatments of 2 and 3% of oil inclusion. In contrast, the treatment of 1% was the one that presented the highest value. The density increased with linseed oil, with the last two treatments (2 and 3%) the ones that presented the highest values and the control treatment and the 1% level the ones that presented the lowest values.

Table 3. Physicochemical characteristics of goat milk fed with linseed oil to replace corn.

Variable	Level of inclusion (%)				*P-value*
	0.0	1.0	2.0	3.0	
Fat(%)	3.29	3.04	3.13	3.16	0.4197
NGS (%)	6.70b	7.37a	6.96ab	7.5ab	0.0302
Density (g /cm3)[1]	1.028b	1.028b	1.029a	1.029a	0.0327
Protein (%)	3.56	3.53	3.53	3.47	0.9426
Lactose (%)[2]	4.37b	4.34b	4.47a	4.50a	0.0273
Cryo index (°C)	0.50	0.51	0.51	0.52	0.3662
Moisture (%)	90.00	89.58	89.92	89.59	0.2326
Ash (%)	0.74	0.74	0.72	0.72	0.9628
pH	6.54	6.51	6.50	6.55	0.7931
Acidity % lactic acid	0.14	0.15	0.14	0.15	0.2351

NGS – Non-greasy solids (%); pH - Hydrogenic Potential; Electrical conductivity – (mS cm^{-1}). Means followed by different letters on the same line differ from each other by Tukey's test at the 5% probability level. [1]$Y = 1.027 + 0.398x$ ($R^2 = 0.76$); [2]$Y = 4.289 + 0.053x$ ($R^2 = 0.76$).

Non-fat solids (NFS) represent the solid part of milk (proteins, lactose, and minerals) except the lipid component. It is relevant to consider that the indexes of these solid components had a significant treatment effect in isolation. Non-fat solids presented values below the normative standard, at least 8.2% (Brasil, 2000). According to Mendes et al. (2009), non-fat solids are one of the parameters most subject to variation, according to the nutritional characteristics of diets, racial characteristics, lactation stage, number of deliveries, climate, and time of year, and udder health status.

El-Shafei et al. (2020) investigated the impact of supplementing goat milk with quinoa extracts in the range of 5, 10 and 15 g / 100 g in the fermentation of milk, note that the supplementation of goats' milk with water or permeate extract of quinoa, particularly at levels of 10 and 15 g/100 g, enhanced the quality of the final products in terms of apparent viscosity, microstructure and organoleptic acceptability. Quinoa extract containing starch can be used as a texture enhancer to overcome the weak texture of goats' milk yoghurt. Furthermore, the supplementation with quinoa permeate extract enhanced the viability of lactic acid bactéria and led to a reduction in the fermentation time, which is considered an important criterion in yoghurt production.

Milk density is associated, in particular, with the concentration of dissolved elements in suspension and with the proportion of fat. Therefore, it must fluctuate with the variation of these constituents (Ribeiro & Ribeiro, 2010). As with the NFS, the density suffered a treatment effect, with values within the normal range, according to current Brazilian legislation, which considers the levels of variation between 1.0289 and 1.0340 (Brasil, 2000). Santos et al. (2019) consider density as the specific weight of the milk, being quite sensitive to changes in volume, in the addition of constituents, skimming, or in the amount of milk solids. These authors investigated the quality of milk from goats submitted to a concentrate diet based on corn bran, wheat bran, cotton cake, and soybean meal; as a source of forage, elephant grass, and palm.

Regressive effects (linear and quadratic) were not observed for any other variables studied, except for lactose and density (Table 3). Thus, lipids are the main component that could be changed with the addition of oil. So, it is known that dietary lipids increase the secretion of milk fat and change the fatty acid composition of milk in lactating goats (Bernard et al., 2015).

The inclusion of 1 to 3% linseed oil to replace corn did not change the total lipid content of the milk. The choice of a maximum value of 3% inclusion of linseed oil is related to the fact that feeding vegetable oils containing unsaturated fatty acids can inhibit ruminal fermentation. A decrease in ruminal nutrient digestion would be an essential factor limiting the amount of flaxseed oil added to diets (González et al., 2020). Therefore, formulations between 1 and 3% linseed oil to replace corn were chosen to meet energy and protein requirements. The increase in lactose may be related to the increase in propionate provided by the oil. This fact was observed by Ye et al. (2009) in work with dairy cows supplemented with flaxseed oil, soybean oil, and extruded soybeans and confirmed by Kholif et al. (2018), who reported an increase in short-chain fatty acids (7.1 and 11.6% for treatments with oil and seeds, respectively) and ruminal propionate (18.3 and 20% for treatments with oil and seeds, respectively), in research with and flaxseed oil in the diets of Anglo-Nubiano goats.

Twenty fatty acids were identified in goat milk, which gives us an important source of information about animal diet and milk quality concerning human health benefits (Table 4).

The inclusion of flaxseed oil in the diets of dairy goats in this study resulted in changes in the fatty acid profile of the milk. Significant changes were observed in 11 fatty acids ($P < 0.05$), and these differences were mainly observed in the saturated fatty acid (SFA) profile, with an average of 62.83% between treatments. Among the FAs, palmitic acid (C16:0) was the most abundant (= 30.54). However, it is essential to emphasize that as linseed oil was included in the diet, the levels of saturated lauric fatty acids (12: 0), myristic (14:0), pentadecyl (15:0), and palmitic (16:0) were decreasing ($P < 0.05$).

Two factors may have caused the reduction in mid-chain SFA. First, the scarcity of acetate and 3-hydroxybutyrate substrates in the blood plasma used for de novo synthesis in the mammary gland may be a consequence of alterations in the rumen microflora caused by the high-fat diet. Second, another factor may be the

Table 4. Lipid profile (%) present in the milk of goats fed with linseed oil to replace corn.

Lipid profile	Levels of inclusion (%)				*P-value*
	0.0	1.0	2.0	3.0	
C8:0	0.73 ± 0.13	0.61 ± 0.11	0.59 ± 0.26	0.72 ± 0.13	0.283
C10:0	7.20 ± 1.73	6.26 ± 0.97	5.74 ± 1.50	5.43 ± 1.67	0.120
C12:0	3.70 ± 1.06a	3.20 ± 0.58ab	2.87± 0.56ab	2.66 ± 0.46b	0.035
C13:0	0.50 ± 0.09	1.00 ± 0.57	0.75 ± 0.58	0.40 ± 0.07	0.302
C14:0	12.06 ± 2.06a	11.68 ± 1.38a	10.66 ± 1.68ab	9.22 ± 1.70b	0.012
C14:1[1]	0.44 ± 0.06a	0.40 ± 0.07ab	0.38 ± 0.07ab	0.32 ± 0.04b	0.002
C15:0	0.90 ± 0.08a	0.82 ± 0.17ab	0.76 ± 0.08ab	0.70 ± 0.12b	0.014
C15:1	0.28 ± 0.02	0.24 ± 0.07	0.23 ± 0.04	0.23 ± 12.79	0.242
C16:0	34.06 ± 3.06a	32.56 ± 5.61	28.96 ± 4.24ab	26.56 ± 2.38b	0.003
C16:1n7	0.51 ± 0.06a	0.42 ± 0.06ab	0.31± 0.16ab	0.26b ± 0.25	0.014
C17:0	0.63 ± 0.08	0.57 ± 0.11	0.59 ± 0.01	0.55 ± 0.90	0.385
C17:1	0.25 ± 0.02	0.24 ± 0.04	0.24 ± 0.00	0.27 ± 0.06	0.643
C18:0	9.93 ± 1.99b	12.93 ± 1.71b	19.47 ± 0.18a	16.37 ± 1.38a	<0.001
C18:1n9	25.80 ± 3.87b	25.99 ± 12.22b	33.38 ± 0.12a	31.60 ± 5.17a	0.025
C18:2n6[2]	1.98b ± 0.47	2.52 ± 0.36ab	2.87 ± 0.02a	2.50 ± 0.39ab	0.033
C18:3n6	0.34 ± 0.01c	0.62b ± 0.11	0.85 ± 0.01a	0.86 ± 0.09a	<0.001
C18:3n3	0.47 ± 0.11	0.69 ± 0.16	0.38 ± 0.02	0.63 ± 0.25	0.121
C20:0[3]	0.21 ± 0.06	0.26 ± 0.02	0.31 ± 0.02	0.32 ± 0.05	0.062
C20:3n3	0.21 ± 0.01a	0.00c ± 0.00	0.16 ± 0.01ab	0.11 ± 0.00b	0.023
C22:1n9	0.41 ± 0.08	0.50 ± 0.14	0.21 ± 0.04	0.44 ± 0.00	0.055
SFA	67.05 ± 4.62a	66.59 ± 10.98a	55.38 ± 5.22b	62.31 ± 5.72ab	0.009
MUFA	21.05 ± 12.45ab	21.05 ± 12.68ab	9.38 ± 15.67b	32.58 ± 5.07a	0.007
PUFA	2.10 ± 1.36ab	2.87 ± 1.84ab	1.07 ± 1.98b	4.00a ± 0.52a	0.005

SFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids. Means followed by different letters on the same line differ from each other by Tukey's test at the 5% probability level. [1]Y = 0.72 – 0.16x (R^2 = 0.6); [2]Y = 0.33 + 1.03x (R^2 = 0.95); [3]Y = 0.01 + 0.11x (R^2 = 0.95).

increased intake of long-chain polyunsaturated fatty acid, which affected crucial enzymes in the de novo pathway, such as acetyl-CoA carboxylase and fatty acid synthesis (Martínez Marín et al., 2011). These results are significant. After all, they indicate a benefit to human health, considering that C12:0, C14:0, and C16:0 are considered harmful because they are directly related to higher concentrations of cholesterol, which may favor the appearance of coronary artery disease (Hanuš et al., 2018).

For stearic acid (18:0) there was an increase ($P < 0.05$) of 30.21%, 96.07% and 64.85% for treatments with 1, 2 and 3% linseed oil , respectively, compared to the control diet. Flaxseed oil is rich in PUFA, which are extensively metabolized by biohydrogenation in the rumen, having stearic acid (C18:0) as the final product. Therefore, this specific transformation pathway may have led to an increase in the C18:0 content found in milk (Borková et al., 2018). Similar results were found in milk after feeding linseed oil to goats (Nudda et al., 2013; Renna et al., 2013; Bernard et al., 2015).

As for unsaturated fatty acids, an increase ($P < 0.05$) of oleic acid (C18:1n9), linoleic acid (C18:2n6), and γ-linolenic acid (C18:3n6) can be noted, with increasing levels of supplementation of linseed oil. Therefore, oleic acid was found in a greater proportion (= 29.19%). The increase in these unsaturated fatty acids in milk may be related to the manipulation of ruminal biohydrogenation by supplementing flaxseed oil, which is rich in unsaturated fatty acids in the diet, favoring a more excellent escape of intermediates before the conversion to stearic acid was completed (Bessa et al., 2000; Bomfim et al., 2011).

The use of vegetable oils, such as linseed oil, increases the content of MUFA, PUFA, and CLA and in a lower proportion of SFA, as well as the lower atherogenicity index (Oliveira et al., 2021), which was also observed in this study because the inclusion of flaxseed oil increased MUFA and PUFA and reduced SFA. Also stating that diets of goats fed with flaxseed oil significantly increase the levels of γ-linolenic acid, which, being ingested by humans, undergoes elongation and desaturation in the body to produce docosahexaenoic acid and eicosapentaenoic acid, which have been shown to reduce blood pressure, blood triglycerides, inflammation and the incidence of cardiovascular disease (Oliveira et al., 2021).

Polyunsaturated fatty acids of the n-6 family (PUFA n-6) are precursors of series 2 prostaglandins and series 4 leukotrienes (associated with pro-inflammatory and prothrombotic activity) (Patterson et al., 2012), while ω-3 PUFAs are precursors of series 3 prostanoids and series 5 leukotrienes (associated with anti-inflammatory and antithrombotic properties).

It is observed that the inclusion of flaxseed oil gradually increased the costs of the total diet, ranging from R$1.28 in the control diet to R$1.47 in the diet with 3% flaxseed oil (Table 5).

Although the diet with 3% flaxseed oil is the most costly, representing an increase of 13% compared to the control diet,

Table 5. Experimental diet costs and profit according to milk yield of goats fed with flashseed oil.

Ingredients	Levels of inclusion (%)			
	0.0	1.0	2.0	3.0
Corn meal(R$/kg)	37.95	36.82	35.69	34.55
Wheat bran (R$/kg)	3.93	3.93	3.93	3.93
Soybean meal (R$/kg)	19.28	19.28	19.28	19.28
Tífton hay (R$/kg)	69.24	69.24	69.24	69.24
Flaxseed Oil (R$/litro)	0.00	8.00	16.00	24.00
Limestone (R$/kg)	0.67	0.67	0.67	0.67
Mineral Supplement (R$/kg)	2.00	2.00	2.00	2.00
Total cost of diet (R$/kg)	1.28	1.34	1.40	1.47
CNM, kg/day	1.88	1.95	1.90	1.73
Milk yield (kg/goat/day)	2.30	2.26	2.25	2.19
Cost of food (R$/day)	2.40	2.61	2.67	2.54
Production gain (R$/day)	5.75	5.65	5.63	5.48
Gross profit (R$/day)	3.35	3.04	2.96	2.94
Gross margin (profit/diet cost)x100	58.23	53.75	52.61	53.69

CNM = consumption in natural matter.

Table 6. Physicochemical characteristics of cheese from goats fed diets containing flaxseed oil to replace corn.

Variable	Levels of inclusion (%)				*P-value*
	0.0	1.0	2.0	3.0	
Moisture	54,61 ± 6,5	51,10 ± 5,5	56,43 ± 5,1	53,39 ± 4,1	0,0662
Protein	21,18 ± 3,8	22,99 ± 1,6	20,79 ± 2,4	21,91 ± 3,8	0,3268
TDE	45,39 ± 6,5	48,90 ± 2,8	43,57 ± 5,1	46,61 ± 4,1	0,0662
Ash	4,51 ± 0,3ab	5,03 ± 0,6a	4,23 ± 0,6b	4,66 ± 0,6ab	0,0071
pH[1]	6,59 ± 0,2	6,55 ± 0,3	6,39 ± 0,5	6,72 ± 0,1	0,0771
Acidity	0,02 ± 0,0	0,02 ± 0,0	0,02 ± 0,0	0,02 ± 0,0	0,3605
Instrumental color					
L*[2]	38,88 ± 1,62ab	40,68 ± 1,10a	40,18 ± 5,60a	38,07±1,70b	0,0019
a*	1,43 ± 0,19b	-1,21 ± 0,15a	-1,42 ± 0,29ab	-1,70 ± 0,12c	<0,0001
b*	9,53 ± 0,72	9,05 ± 0,21	9,59 ± 1,06	9,63 ± 0,90	0,2576

TDE – Total dry extract; pH - Hydrogenic Potential. Means followed by different letters on the same line differ from each other by Tukey's test at the 5% probability level. [1]$Y = 6.970 - 0.441x + 0.093x^2$ ($R^2 = 0.66$); [2]$Y = 35.31 + 4.59x - 0.98\ x^2$ ($R^2 = 0.99$).

this difference drops to 5.57% when considering the costs of feed based on the average of dry matter intake. Furthermore, based on feed efficiency, the diet with 3% flaxseed oil showed the best result. The maintenance of milk production among the studied diets, associated with the increase in the cost of feeding, resulted in reduced profits in the linseed oil diets. However, it is essential to emphasize that the gross margin of all diets presented values above 52%. Gonçalves et al. (2008) state that feeds costs represents 60 to 70% of the total cost in the dairy goat production system. Furthermore, diets with flaxseed oil showed improvements in the lipid composition of milk, presenting relevant characteristics for human health, thus adding value to the final product.

There was a significant effect for ash (P = 0.0071) with the inclusion of flaxseed oil in the goats' diet (Table 6). The ash content of this research ranged between 4.23 and 5.03, and the treatment with 1% oil had the highest value for ash, and the other groups were statistically similar. It seems relevant to point out in Table 6 that the treatment in which the animals consumed 2% oil to replace corn presented cheeses with the highest percentage of moisture (56.43%) and the lowest ash content (4.23%). In comparison, the treatment with 1% linseed oil showed moisture content of 51.10% and ash content higher between treatments, 5.03, showing that the water content of the cheese may have had a significant influence on the amount of ash in the samples than the addition of linseed oil.

The Technical Regulation of Identity and Quality of the *coalho* cheese establishes that the moisture content must be medium to high moisture, with values ranging from 36.0 to 54.9% (Brasil, 2001). Table 6 shows a variation between 51.10 and 56.43, with high humidity, with a maximum value of 56.43, a little above the maximum established by the regulation.

We observed that the cheeses produced in this experiment had low brightness values (L*), with diets with 1 and 2% linseed oil providing the highest values among treatments (Table 6). However, the L* parameter indicates luminosity and refers to the object's ability to reflect or transmit light, ranging on a scale from zero to 100; that is, the higher the L* value, the brighter the object (Nobre et al., 2020). An explanation for this may be related to the moisture content of the cheeses, which averaged 53.88%, given that luminosity is related to the water's ability to reflect incident light (Figueiredo et al., 2015).

The a* color parameter indicates the intensity of red and green colors. Negative values indicate greater green color intensity, and the positive part of the scale indicates red. These results show us that the highest level of linseed oil inclusion, 3%, induced a drop in this parameter, indicating a greater intensity of green color. The color of the cheese is closely linked to milk fat, and that this is due to the ability of fatty acids to solubilize compounds such as carotenoids. While the b* color parameter (yellow/blue) was not influenced ($P > 0.05$) by the experimental diets. On this scale, positive values indicate the presence of a yellow color present in the cheese. However, very low values indicate the yellowish-white color characteristic of *coalho* cheese. In this sense, it is important to emphasize that color works as the first quality indicator evaluated by consumers, being essential for product acceptance, even before it is tasted (Fuquay et al., 2011).

4 Conclusion

The addition of linseed oil linearly increased the non-fat solids content and milk density. As a result, there were changes in the lipid profile of milk, decreasing saturated fatty acids and increasing unsaturated fatty acids, resulting in health-promoting effects. The cheese was linearly altered only in pH and color values.

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