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Effect of the feeding system on yield, chemical composition, and fatty acid profile of artisan cheese from local goat milk in northern Mexico

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Abstract

The objective of this research work was to determine the yield, texture, and quality of artisan goat cheese produced in a housed and extensive grazing production system in northern Mexico. Milk from ten adult local goats, at the beginning of lactation, with an average weight of 42±2.25 kg and 2.5 births, randomly distributed in two treatments (housed n=5 and grazing n=5), was used to make cheese. The goats had an adaptation period of 14 days and were milked manually for 28 days. Yield, texture, chemical composition (concentration of fat, protein, moisture, salt, and total solids), and fatty acid profile of the cheese were evaluated. Statistical analysis was performed as a repeated measures design with the MIXED procedure. The fatty acid profile was analyzed by one-factor ANOVA with the GLM procedure and the comparison of means was performed with Tukey's test ($p<0.05$). There were differences between treatments, with higher values ($p<0.05$) under the housed system for milk yield, cheese yield, fat concentration (22.281 %), protein (20.173 %), total solids (45.162 %), salt (0.966 %), saturated fatty acids ($p<0.001$), and textural parameters ($p<0.05$). Under grazing, there was an increase in conjugated linoleic ($p<0.001$), cis-10-heptadecanoic ($p=0.001$), heptadecanoic acid ($p=0.001$), acid oleic ($p<0.001$), elaidic ($p<0.001$), and α-linolenic ($p<0.001$) acids. It is concluded that the extensive grazing production system offers better benefits regarding nutritional quality of cheese, highlighting conjugated linoleic acid and milk fat, although with a negative effect on milk production. By linking product quality to husbandry practices and breed resources, the research provides an evidence base for reinforcing traditional cheese making as a driver of economic resilience, cultural continuity, and agro ecosystem sustainability in northern Mexico.

Keywords: conjugated linoleic acid; fat; local breeds; texture profile; yield

Introduction

Artisan goat cheeses are increasingly recognized not merely as gourmet delicacies but as pillars of rural livelihoods, territorial identity, and agro biodiversity conservation (Torres-Hernández et al., 2021). Their distinctive visual, textural, and aromatic attributes arise from a close coupling of native forage resources, extensive grazing practices, and the unique genetic adaptations of local goat breeds (Ramirez-Rivera et al., 2021; Chávez-Servín et al., 2018). When goats consume a botanically diverse rangeland diet, the resulting milk is enriched with bioactive lipids - most notably conjugated linoleic acid - linked to human health benefits such as anti-carcinogenic and anti-diabetic effects (Nudda et al., 2021; Zongo et al., 2021). The fatty acids (FA) in cheese originate primarily from milk fat. Cheese lipids contain saturated (SFA), monounsaturated (MUFA), and polyunsaturated (PUFA) fatty acids, and their content and proportion depend on various factors, such as the type and characteristics of the milk and the cheese-making method (Barać et al., 2025). For smallholders operating in semi-arid landscapes, extensive grazing is therefore not only a cost effective feeding strategy, but also a value adding practice that differentiates their cheeses in increasingly nutrition conscious markets (Galina et al., 2019). Goat cheeses are commonly produced by small producers who play an important role in local and national economic sustenance, contributing to the improvement of the quality of life of both producers and consumers (Klir Šalavardić et al., 2024).

The endemic "Criollo" goat populations that underpin this system have co-evolved with harsh environments, displaying genetic traits - heat tolerance, disease resilience, efficient forage utilization - that make them indispensable to climate smart livestock production (Torres-Hernández et al., 2021). By valorizing their milk through traditional cheese making, producers safeguard these genetic resources while generating stable income streams that circulate within local economies, support women's entrepreneurship, and curb rural out migration (Granados-Rivera et al., 2022). Moreover, artisanal dairies transmit craft knowledge across generations, reinforcing cultural heritage and gastronomic tourism, both of which are central to diversified regional development strategies (Ricardo et al., 2025).

There is no precise information on artisanal cheese production due to the lack of official records; however, it is estimated that artisanal cheeses represent around 75 % of the country's total cheese production (Reyes-Díaz et al., 2025). The country specializes in producing high-quality cheeses that are renowned for their distinctive flavor profiles and have received international recognition (Ricardo et al., 2025). A notable example is Queso Kabry, which won the World Cheese Awards' Best Cheese in Latin America prize (Reyes-Díaz et al., 2025). However, empirical data on major dairy production centers such as Comarca Lagunera, in northern Mexico, remains scarce. Preliminary evidence indicates that cheeses manufactured from grazing herds offer superior protein content, whereas stall fed systems may enhance fat and mineral fractions (Rangel-Ortega et al., 2024). Yet the broader socio economic, nutritional, and environmental implications of these production geometries are still poorly quantified. Addressing this knowledge gap is critical for designing policies that simultaneously conserve native breeds, strengthen rural economies, and meet consumer demand for health promoting foods. Under this scenario, there are Mexican cheese varieties that, while less known, are of great importance to their production regions since, beyond economic and nutritional aspects, they have special characteristics that make them genuine products that must be recognized, particularly if they have functional properties. Thus, the objective of this study is to evaluate yield, chemical composition, and FA profile of artisanal goat cheese in northern Mexico, with focus centered on the effect of grazing versus housing.

Materials and methods

The experiment has been evaluated and approved by the Animal Welfare Committee of the Colegio de Postgraduados Protocol COBIAN/013/23.

Location

The study was carried out in a production unit located in the ejido Ignacio Zaragoza, Municipality of Viesca, Coahuila, in the region known as Comarca Lagunera, which is located at 24° N and 104° W, at 1100 m above sea level. The climate is desert, semi-warm with cool winters; mean annual temperature is 25 °C and mean annual rainfall is 240 mm.

Animals and treatments

In this study, milk was used from 10 local "Criollo" goats (crossbreeds Alpine × Saanen × Toggenburg) at the beginning of lactation, with an average live weight of 42±2.25 kg and 2.5 births, randomly distributed into two treatments: housed system (n = 5) and extensive grazing (n = 5). The animals had an adaptation period of 14 days and an experimental period of 28 days. Goats in the housed system were kept in individual shaded pens (2×3 m) equipped with individual feeders and waterers, with water available *ad libitum*. They were offered 2.5 kg dry matter (DM) per goat per day of a ration based on forage and concentrate, divided into two equal meals at 08:00 and 16:00 h, formulated according to the nutritional requirements for lactating dairy goats (NRC, 2007). Rations were offered individually, and feed refusals were collected and weighed daily before the morning. Feed allowances were adjusted weekly according to each goat's live weight to maintain consistent intake levels (Table 1). Goats in the grazing system were herded daily to native rangeland pastures and allowed to graze from 12:00 to 18:00 h, covering approximately 4-8 km day^{-1}. From the end of the grazing period (18:00 h) until departure the next day (12:00 h), the goats were kept in pens where they had access to water *ad libitum* and did not receive any additional feed supplementation.

The experiment was arranged in a completely randomized design with two feeding systems (housed vs. grazing). For milk yield and composition, the experimental unit was the individual goat (n = 5 per treatment). Measurements were taken once daily throughout the experimental period, and weekly composite samples were prepared for milk composition and cheese manufacture as described below.

Chemical composition of the concentrate and forage

Forage was sampled in weeks 1, 3, and 6, and composite samples were prepared for each species; throughout the grazing route, 300 g of each forage species. Regarding the concentrate, different samples were taken from the total mixed ration and composite samples were prepared. The forage and concentrate samples were dried and subsequently processed in a Thomas WILEY mill (Model 4, Laboratory Mill), with 1 mm mesh, for subsequent analysis.

The grazed rangeland consisted of *C. virgata, C. dactylon, P. bipinnatifidum, Acacia* spp., *C. berlandieri*, and *S. elaeagnifolium*. Botanical composition was estimated using quadrat sampling: 0.5-m^2 quadrats were systematically placed along the grazing route each week; species-level biomass was clipped at around 2 cm, simulating the animal's bite, oven-dried (60 °C, 48 h), and expressed as g DM m^{-2}. Sampling took place during the early dry season when the stand was mostly mature: grasses were actively tillering, and forbs and shrubs were leafy and flowering. This phenological context is important for understanding the FA profile and protein content of the forage offered. Bite-count and focal-scan observations (10-min bouts per goat; five goats per group; six observation days) revealed a higher preference for *Accacia* spp. and *C. virgata* inflorescences, and avoidance of *C. dactylon*. Therefore, chemical analyses focused on the species that were preferred (composite by preference).

The ingredients in the diet of the housed goats consisted of alfalfa, oats, and concentrate. The analyses of the chemical composition of the concentrate and forage samples were: dry matter (DM) (AOAC 925.45), organic matter (OM) which was calculated by difference, total protein (TP) (AOAC 991.20), ethereal extract (EE) (AOAC 989.08), ashes (AOAC 938.08) (AOAC 2005), neutral detergent fiber (NDF), and acid detergent fiber (ADF) (Van Soest et al., 1991).

Milk yield and composition

Goats from both treatments were manually milked once a day at 06:00 h throughout the 28-day experimental period. Immediately after milking, individual milk yield (kg day^{-1}) was recorded using a portable digital scale. Fat-corrected milk (4 % FCM) was calculated according to NRC (2001) using the equation:

4 % FCM (kg day^{-1}) = 0.4 × milk yield (kg day^{-1}) + 15 × milk fat (kg day^{-1}).

For each goat, a weekly composite milk sample (100 mL) was prepared by pooling proportional aliquots from the seven daily milkings to obtain a representative sample of the week. Immediately after sampling, the milk was cooled to 4 °C and preserved with bronopol according to the manufacturer's recommendation. Preserved samples were stored at 4 °C for no longer than 7 days before analysis. During storage, the samples were kept in sealed vials and protected from light to limit lipolysis and microbial growth.

Before analysis, the milk was gently mixed and filtered through a clean cloth to remove visible impurities that could interfere with the measurements. Milk fat, protein, and lactose contents were determined on the weekly composite samples by mid-infrared spectroscopy using an automatic milk analyzer, following the manufacturer's instructions. All analyses were performed in duplicate, and mean values were used for statistical analysis. All samples from both feeding systems were collected, preserved, stored, and analyzed under identical conditions.

Cheese making process

The fresh cheese was made with a mixture composed of milk collected during the week, simulating the artisanal process of the region.

A total of 92.53 L^{-1} of milk was processed with a total of 9 samples of fresh cheeses produced for goats in the housed system, while for the grazing goats, a total of 51.37 L^{-1} was processed and 7 samples of fresh cheeses. The milk was placed in a stainless steel container of 30 L capacity to carry out pasteurization at 63 °C/30 min^{-1}, after which time it was allowed to cool to a temperature of 40 °C. Commercial rennet was added (coagulation strength 280 IMCU mL^{-1}, from Cuamex Industries, Mexico), prepared according to the supplier's instructions, adding 10 mL per 100 L^{-1} of milk. The coagulation time was 40 min at room temperature. After the coagulation period, the curd was cut into cubes of approximately 3 cm with a stainless steel knife vertically and horizontally. It was manually agitated for 30 min to gradually release the whey, then a partial draining of 3/4 was carried out and then NaCl (600 g/100 L^{-1}) was added, mixing thoroughly. The curds were placed in plastic molds and allowed to press under their own weight, turning them every 20 min for 1 h. Subsequently, the cheeses were covered with sterilized polyethylene paper and refrigerated for 18 to 24 h at 4 °C. The cheeses were weighed and placed in a freezer at -20 °C for their respective analyses.

Cheese yield was determined by considering the wet fraction of the cheese, which is the actual yield and was calculated according to the equation of Hu et al. (2013). Meanwhile, the one excluding this fraction is the dry matter adjusted yield and was obtained following the equation of Fenelon and Guinee (1999).

Fatty acid profile

A total of 16 cheese samples and 7 food samples were analyzed for FA analysis. Freeze-drying of cheese: 40 g of cheese was weighed into amber vials, which were frozen

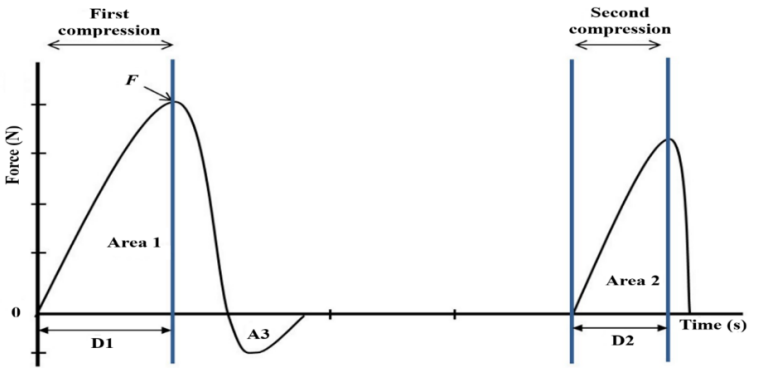

Figure 1. Texture profile analysis (TPA) curve. Calculations of the textural properties: hardness = F (N), adhesiveness = A3 (N s), cohesiveness = A2/A1 (dimensionless), elasticity = D1/D2 (dimensionless), and chewiness = hardness x cohesiveness x elasticity (N). Taken from Torres-Salas et al. (2023)

at -80 °C. They were then placed in a Labconco® lyophilizer, (FreeZone 6, USA), attached to a Vacuubrand® RZ 9 vacuum pump. Lyophilization was carried out at a vacuum point of 0.010 mBar for 48 h at -49 °C. The samples were stored under refrigeration for FA analysis.

Subsequently, the FA profile of the cheese was determined in the Animal Nutrition laboratory of the Livestock Program of the Colegio de Postgraduados, Campus Montecillo, Texcoco, State of Mexico. The FA extraction was performed according to the methodology of Feng et al. (2004). The FA profile was determined using the modified methylation technique of Palmquist and Jenkins (2003) and Jenkins (2010), in which FAs are in the form of methyl esters. For this purpose, 0.5 g of freeze-dried cheese sample and 0.5 g of forage and concentrate samples were used, which were placed in 50 ml culture tubes with bakelite caps. Three mL of sodium methoxide (Sigma-Aldrich catalog 403067-250) (0.5 M in methanol to protect the isomerization process of the unsaturated FAs) was added, and vortexed gently to mix. The tubes containing the cheese samples were placed in a water bath at 50 °C for 10 min and then allowed to cool for 5 min. Subsequently, 3 mL of 5 % methanolic hydrochloric acid was added, capped, and vortexed slightly. The tubes were placed in a water bath at 80 °C for 10 min and allowed to cool for 7 min. Then, 3 mL of hexane was added to dissolve and extract only the fat and 5 mL of 6 % potassium carbonate to saponify and release the FAs and neutralize the reaction. The samples were vortexed and the contents were emptied into 16.5 mL polypropylene tubes and centrifuged (Beckman J2-HS, USA), at 1233 g for 10 min. The organic phase was then extracted and placed in another polypropylene tube containing 0.5 g of sodium sulfate and 0.1 g of activated carbon to remove impurities. It was vortexed and centrifuged (Beckman J2-HS, USA), at 629 g for 10 min. The sample was then extracted and filtered through an acrodisc (Thermo Scientific, titan 44513-NN, 17 mm green filter and 0.45 µm nylon membrane; to ensure an impurity-free sample) and placed in a vial where it was stored at -20 °C until analysis by gas chromatography. FA methyl esters were determined on a Hewlett Packard 6890 chromatograph with automatic injector with a silica capillary column (100 m x 0.25 mm x 0.20 µm thick, Sp-2560, Supelco, USA) and helium as carrier gas. The column temperature was programmed at 140 °C for 2.95 minutes, increasing to 210 °C at a rate of 3 °C/min and subsequently to 235 °C at a rate of 0.7 °C/min. Run time: 62 minutes. The identification of the FAs was performed by comparing the retention times of each peak obtained from the chromatogram with a standard of 37 FA peaks from the Supelco company.

Cheese chemical composition

The determination of protein, fat, moisture, salt, and total solids in cheese was performed by near infrared transmission (NIT) that transmits light through the cheese sample with a FoodScan™Lab analyzer (FOSS Analytical AB, Hillerød, Denmark), in the Multipurpose Laboratory of the Autonomous University of Chapingo, Texcoco, State of Mexico, using a 100 g sample of cheese.

Texture profile analysis (TPA)

Texture profile analysis (TPA) was performed at the Department of Agroindustrial Engineering in the Sensory Analysis Laboratory of the Universidad Autónoma Chapingo, Texcoco, State of Mexico. TPA was performed using the method described by Hernández-Morales et al. (2010), using a TA Xt2i texture analyzer (Stable Micro Systems; Surrey, UK) with a 5 kg load cell. The samples (25 mm diameter and height cylinders) were uniaxially compressed at 50 % strain using a 50 mm diameter acrylic disk and a pre- and pos-test head testing speed of 1 mm/s^{-1}. The data from the double compression allowed obtaining force/time curves from which the APT parameters were calculated: Hardness which is the peak force (F) of area one (A1) of the first compression. Adhesiveness which represents the work required to remove the disc compressing the sample and corresponds to area three (A3). Cohesiveness, defined as the property that allows the cheese to remain attached after a first compression and is calculated as the ratio of area two to area one (A2/A1). Elasticity refers to the ability of the cheese to return to its original height after a first compression and is calculated by dividing distance two by distance one (D2/D1). Finally, chewiness refers to the work required to perform a double compression and corresponds to the product of F * (A2/A1) * (D2/D1). The calculations of the APT properties were calculated as follows: *Hardness* = F (N), *Adhesivity* = A3 (N-s), *Cohesivity* = A2/A1 (dimensionless), *Elasticity* = D1/D2 (dimensionless), and *Chewability* = hardness x cohesivity x elasticity (N) (Torres-Salas et al., 2023) (Figure 1).

Statistical analysis

The data obtained from the variables protein, fat, moisture, salt, total solids, actual and adjusted cheese yield, and textural parameters, were analyzed in a completely randomized design in a repeated measures arrangement with the MIXED procedure of the SAS v.9.4 statistical software. The Bartlett test was performed to determine the homogeneity of variances of the data. The Bayesian information criteria of Schwartz and Akaike were used to determine the most appropriate covariance structure. The FA profile information was analyzed using a one-factor ANOVA with the GLM procedure and the comparison of means was performed with Tukey's test. The general structure of the model is as follows:

$Y_{ijkl}=\mu + R_{i(j)} + T_j + S_k + T_j*S_k + E_{ijkl}$

Where:

Y_{ijkl}: Actual and adjusted yield and content of chemical components (fat, protein, moisture, salt, and total solids).

μ: Constant characterizing the population

$R_{i(j)}$: Random effect of the i-th cheese nested within treatment (i=1,2)

T_j: Fixed effect of the jth treatment (j=1, 2)

S_k: Fixed effect of the k-th week of treatment (k=1...4)

T_j*S_k: Treatment*week interaction effect.

E_{ijkl}: random error, which was assumed for all components normally distributed with zero mean and common variance.

Results and discussion

The forage species consumed during the route were *Chloris virgata*, *Cynodon dactylon*, *Parthenium bipinnatifidum*, *Acacia* spp., *Chenopodium berlandier*), and *Solanum elaeagnifolium*, whose chemical composition is shown in Table 1. Additionally, the FA profiles of the diet consumed by the housed animals and of the forage consumed by the grazing animals were determined (Table 2).

Milk

Milk yield, fat-corrected milk, and its chemical composition were different between treatments ($p<0.05$) (Table 3).

Milk and fat-corrected milk production increased by 96.767 % and 89.164 %, respectively, in housed goats compared to grazing goats ($p<0.05$). This increase is attributed to concentrate consumption, which increases the production of propionate in the rumen, converting it into glucose in the liver and transforming it into lactose in the mammary gland (Hills et al., 2015), generating greater water movement to the mammary secretory cells, and consequently greater milk volume (Otaru et al., 2020). Overall, the higher milk and fat-corrected milk yields observed in housed goats indicate that the stall-feeding system provided a more stable energy supply than the native rangeland available to grazing goats. The concentrate-based ration likely supported greater dry matter intake and a more favorable energy balance, which in turn enhanced mammary secretory activity. Similar patterns

Table 1. *Ingredients and chemical composition of animal diets in housed and grazing systems*

Housed goats diet							
Ingredients					**Inclusion (%)**		
Alfalfa hay					40		
Oat hay					25		
Concentrated feed					35		
Chemical composition (% DM)							
	Concentrate				Forage		
Dry matter	94.56				94.39		
Organic matter	91.47				87.49		
Ashes	8.53				12.51		
Crude protein	12.77				12.64		
Ethereal extract	1.76				3.25		
Neutral detergent fiber	28.48				26.92		
Acid detergent fiber	27.15				24.91		
Grazing goats diet							
Forage	**DM**	**OM**	**ASHES**	**CP**	**EE**	**NDF**	**ADF**
Chloris virgata	94.39	87.72	12.28	4.73	1.16	33.57	32.49
Cynodon dactylon	94.34	90.51	9.49	6.59	1.10	32.29	30.56
Parthenium bipinnatifidum	93.59	85.37	14.63	18.41	6.02	14.04	13.16
Acacia spp.	93.96	89.77	10.24	18.98	5.44	18.59	17.94
Chenopodium berlandieri	94.95	83.99	16.01	14.91	2.82	28.97	26.74
Solanum elaeagnifolium	95.12	87.58	12.42	12.23	2.96	34.07	28.59

DM - dry matter; OM - organic matter; CP - crude protein; EE - ethereal extract; NDF - neutral detergent fiber; ADF - acid detergent fiber.

have been reported in goat dairy, where housed or mixed systems (stall-feeding plus limited pasture) increased milk volume and fat-corrected milk compared with animals relying exclusively on grazing (Granados-Rivera et al., 2022). These results suggest that, under the semi-arid conditions of the Comarca Lagunera, housing with a controlled ration can be an effective strategy to maximize milk yield in local Criollo goats, although at the cost of higher feed inputs.

In the case of milk production in grazing, this decreases due to the energy expenditure caused by the displacement during the search for forage (Lachica and Aguilera, 2005), which is also associated with the low availability and quality of forage that generates an energy and protein deficit, causing the goats to use their body reserves (Goetsch, 2019), thus leading the proteins of the animal's muscle fibers to be mobilized from the synthesis of milk components decreasing milk production (Ramírez-Rivera et al., 2019).

Milk fat concentration was 4.330 % higher in grazing ($p=0.027$). This result is due to fiber intake. In this sense, the forages present a higher concentration of galactolipids, specifically linoleic acid (C18:2 *c*9, *c*12) and α-linolenic acid (C18:3) (D'Urso et al., 2008) which are hydrolyzed to glycerol, FA, and galactose, the latter is rapidly fermented and transformed into volatile fatty acids (VFA). Thus, it can be inferred that the increase in milk fat production in grazing goats was due, in part, to the greater production of acetic acid, a key precursor to the synthesis of milk fat (Seymour et al., 2005).

Protein was higher in milk from housed goats ($p<0.001$), with an increase of 14.482 % with respect to grazing goats ($p<0.05$). The carbohydrates in the feed consumed by the animals are easily fermentable, so there is greater production of energy, propionic acid, and microbial protein (Ángeles-Hernández et al., 2020). This, in turn, leads to changes in the animal's body signals, increasing the concentration of insulin in the blood, which generates changes in the mammary gland favoring the concentration of protein in the milk of housed goats (Jenkins and McGuire, 2006). On the other hand, dietary protein in animals includes nitrogen (N), present as true protein, which is broken down into amino acids and ammonia and used by rumen microorganisms for the synthesis of microbial proteins necessary for protein synthesis in milk (Lu et al., 2019).

Lactose production was higher in the milk of goats in the housed system ($p<0.001$) with respect to those in grazing. In this regard, concentrated feeds generate higher proportions of propionic acid in the rumen (Maldini and Allen, 2019), which serves as the substrate for the production of glucose (Kittivachra et al. 2007), the main precursor of lactose synthesis by mammary gland cells (Otaru et al., 2020), consequently increasing lactose production in the milk of housed goats.

It is interesting to note that there were significant interactions over time in milk fat concentration, which decreased during the experimental period. Regarding protein and lactose, they showed an increase for both treatments ($p<0.05$) (Figure 2). This behavior is associated with a negative correlation between milk production and its components, i.e. as milk production increases, protein and lactose also increase, while fat content decreases due to a dilution effect (Morand-Fehr et al., 2007).

Table 2. *Fatty acid profile (g/100 g of FA) of diets for animals in housed and grazing systems*

Fatty acid	Diet	*Cv*	*Cd*	*Pb*	*Acacia* spp.	*Chb*	*Se*
C12:0	0.817	2.679	2.136	0.952	2.141	0.526	0.746
C14:0	0.706	2.965	1.556	0.948	2.048	0.423	1.087
C15:0	ND	0.853	ND	0.613	0.156	0.176	0.237
C16:0	24.598	38.180	27.170	25.139	25.736	24.357	21.753
C16:1 *cis-9*	0.195	1.440	ND	0.167	ND	0.220	0.43
C17:0	0.167	1.022	0.561	0.205	0.585	0.318	0.803
C18:0	3.366	4.852	3.880	2.912	8.879	3.613	6.179
C18:1 *trans*-9	0.314	1.171	ND	ND	ND	ND	ND
C18:1 *cis-9*	17.763	6.649	13.170	3.205	3.394	9.626	3.875
C18:2*cis-9, cis-12*	38.705	18.597	24.732	23.273	11.660	26.543	26.412
C18:3 *cis-9, cis-12, cis-15*	8.542	8.564	17.389	28.196	32.093	26.355	30.975
C20:0	0.497	3.668	2.918	1.076	1.913	0.753	0.983
C22:0	0.292	3.075	1.663	0.820	0.655	1.071	1.016
C23:0	ND	ND	ND	0.104	1.145	0.696	0.405
C24:0	0.362	2.593	1.878	1.884	0.717	1.263	0.934

ND - Not detected; FA - Fatty acid; Cv - Chloris virgate; Cd - Cynodon dactylon; Pb - Parthenium bipinnatifidum; Chb - Chenopodium berlandieri; Se - Solanum elaeagnifolium.

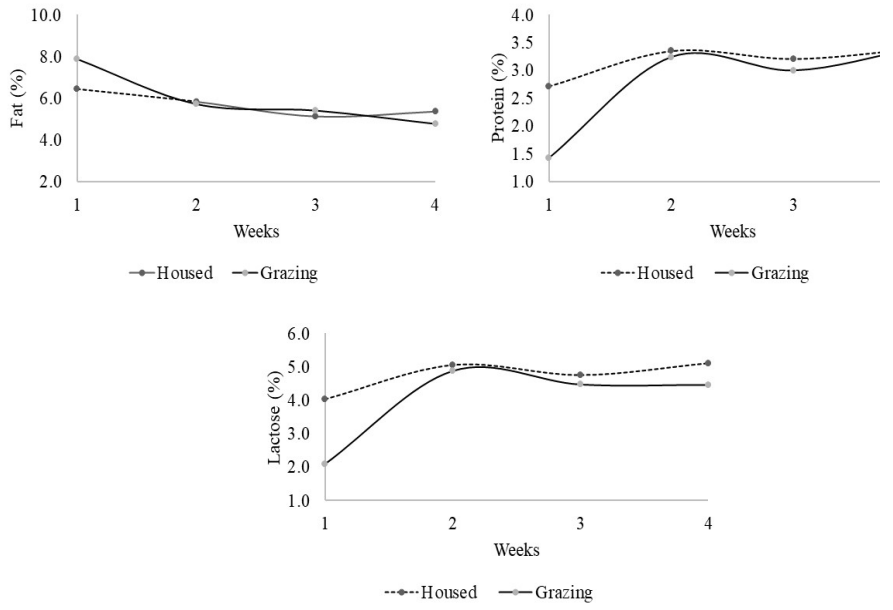

Figure 2. *Concentration of fat, protein and lactose in milk from local goats in housed and grazing systems during the 4-week experimental period (weekly measurements, weeks 1-4)*

Cheese

The chemical composition and yield of the cheese were different between treatments ($p<0.05$) (Table 4). The concentration of fat, protein, salt, and total solids, showed an increase of 5.662 %, 23.503 %, 23.529 % and 9.784 %, respectively, in cheeses from housed goats with respect to grazing goats ($p<0.05$). The above is related to the caseins and fat molecules that were transferred from milk to cheese during the manufacturing process (Cuchillo et al., 2010), which begins with the hydrolysis of κ-casein due to enzymatic action, this destabilizes the casein micelles, which then aggregate to form a gel or curd network that primarily traps fat and protein globules. Once the curd has formed, the syneresis process begins, where the casein network contracts, trapping the fat and protein within the matrix. These fats and proteins are then transferred to the cheese, while much of the lactose and minerals are lost in the whey during the drainage process (Ribak. 2014). Zervas and Tsiplakou (2011) reported that cheese quality depends to a large extent on the composition of the milk, mainly the fat and protein content. Regarding the fat component, it was significantly higher in cheese from housed goats. This result is due to the fact that the casein network traps the milk fat, having a higher fat recovery in the curd (Pazzola et al., 2019).

The cheeses for both production systems presented moisture contents higher than 50 %, classifying them as soft cheeses, in which the basket molds are stacked for self-pressing, in addition to being characterized by rennet action and slow draining (Jiménez-Maroto and Ibáñez, 2023). According to Mexican regulations (NOM-223-SCFI/SAGARPA-2018 and NOM-121-SSA1-1994), the cheeses analyzed are classified as fresh cheeses, which are characterized by high moisture contents, unripened, lacking thin rind, short shelf life, and ready for consumption immediately after production.

Table 3. *Production and chemical composition of milk from local housed and grazing goats*

Variables	Treatments		SEM	*P*-Value		
	Housed	Grazing		Treat	Time	Treat*time
Milk						
Milk production (kg d^{-1})	0.974[a]	0.495[b]	0.096	0.007	<0.001	0.382
Corrected milk production (4 % fat kg d^{-1})	1.222[a]	0.646[b]	0.001	<0.001	<0.001	<0.001
Milk composition (%)						
Fat	5.680[b]	5.926[a]	0.029	0.027	<0.001	<0.001
Protein	3.162[a]	2.762[b]	0.007	<0.001	<0.001	<0.001
Lactose	4.727[a]	3.971[b]	0.007	<0.001	<0.001	<0.001
Milk yield (g d^{-1})						
Fat	55.402[a]	29.772[b]	0.208	0.001	<0.001	<0.001
Protein	30.781[a]	13.453[b]	0.002	<0.001	<0.001	<0.001
Lactose	46.012[a]	19.441[b]	0.028	<0.001	<0.001	<0.001

[ab]*Different letters between columns indicate a difference ($p<0.05$). SEM - standard error of the mean.*

Table 4. Chemical composition of cheese from local housed and grazing goats

Variables	Treatments		SEM	*P*-Value		
	Housed	Grazing		Treat	Time	Treat*time
Cheese						
Cheese composition (%)						
Fat	22.281[a]	21.087[b]	0.140	0.024	<0.001	0.015
Protein	20.173[a]	16.334[b]	0.101	0.004	<0.001	<0.001
Moisture	54.519[b]	58.842[a]	0.121	<0.001	0.009	0.162
Salt	0.966[a]	0.782[b]	0.021	<0.001	<0.001	0.021
Total solids	45.162[a]	41.137[b]	0.053	<0.001	0.069	0.010
Cheese yield						
Real (kg cheese/100 kg milk)	16.731[a]	16.543[b]	0.001	<0.001	<0.001	<0.001
Adjusted for dry matter (%)	7.580[a]	6.810[b]	0.002	<0.001	<0.001	<0.001

[ab]*Different letters between columns indicate a difference (p<0.05). SEM - standard error of the mean.*

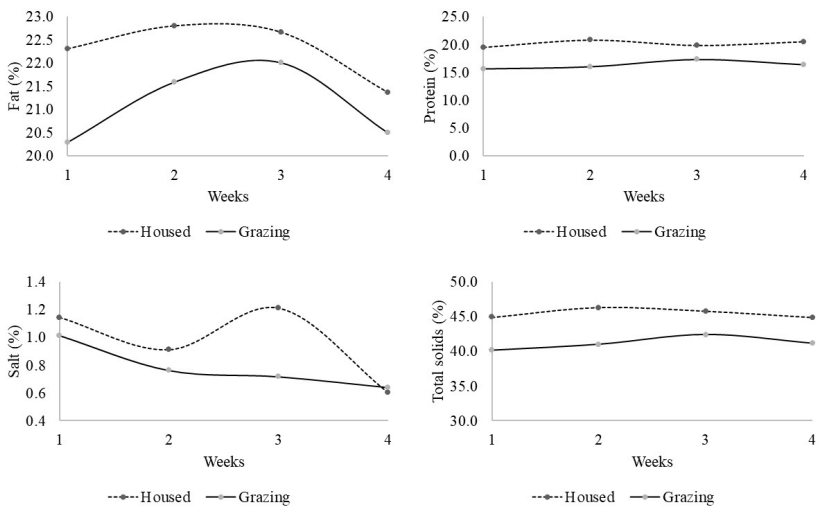

Figure 3. Concentration of fat, protein, salt, and total solids in cheese from local goats in housed and grazing systems during the 4-week experimental period (weekly measurements, weeks 1-4)

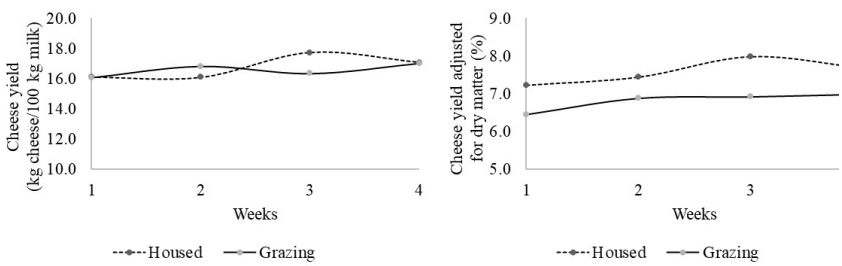

Figure 4. Real and dry matter-adjusted cheese yield from local goats in housed and grazing systems during the 4-week experimental period (weekly measurements, weeks 1-4)

Interactions over time were found in cheese chemical components (p<0.05) (Figure 3). Fat concentration had an increase until week three with a decrease at week four. Protein and total solids concentrations remained stable while salt dereased during the experimental period.

Cheese yield over time was higher in housed goats (p<0.001), with an increase of 1.136 % higher than those on grazing (Figure 4). This increase is attributed to the fact that whey proteins that form complexes with κ-casein form a gel that traps fat and are retained in the cheese curd which contributes to an increase in yield (Rangel-Ortega et al., 2024). In this research, a higher protein content was found in the milk of housed goats, which probably contributed to the increase in cheese yield. In this regard, Fekadu et al. (2005) reported that there is a positive correlation between fat concentration and cheese yield. This means that the higher the fat and protein concentration, the higher the cheese yield and vice versa.

The main ingredient of the diet of grazing goats is forages, so greater amounts of unsaturated FA are transferred to dairy products such as cheese (Delgadillo-Puga et al., 2021). In this sense, the FA profile of the cheese was different between production systems (p<0.05) (Table 4). The cheese FA with the highest concentrations in both systems were

capric (C10:0), lauric (C12:0), myristic (C14:0), palmitic (C16:0), stearic (C18:0), and oleic (C18:1c-9), which represent 84.991% in housed goats and 83.553 % in grazing.

The concentration of SFA was lower in cheeses from grazing goats ($p<0.001$). According to Serrapica et al. (2020), this result is attributed to the fact that with forage-based diets there is a reduced synthesis of short- and medium-chain SFA in the mammary gland, due to the high levels of PUFA in the fresh forage diet that compete with SFA in de *novo* synthesis for esterification in the mammary gland.

MUFA had an increase of 34.183 % in cheese from grazing goats ($p<0.001$), with respect to those from housed goats, among which cis-10-heptadecanoic (C17:1), oleic (C18:1 *c*9), and elaidic (C18:1 *t*9) acids stand out. To this respect, grazing can improve the environment for rumen bacteria, leading to an increase in odd-chain FA like C17:1. Grazing increases microbial diversity and abundance, and the types of bacteria present are responsible for synthesizing these FA, which are then incorporated into milk. At the same time, for PUFA, C18:3 and CLA were higher for grazing goats ($p<0.001$). The presence of PUFA in cheeses, especially those with potentially favorable effects on human health, depends mainly on the FA composition of the milk used (Dauber et al. 2021). Grazing goats fed native forages produce milk richer in MUFA and PUFA, especially C18:1 *c*9, CLA, and C18:3 (Coppa et al., 2011). The above because forages contain more α-linolenic acid, a precursor of vaccenic acid (VA) in the rumen, which is subsequently converted to rumenic acid (RA) in the mammary gland through Δ9-desaturase (Renes et al., 2020), thus generating a higher concentration of CLA in milk from grazing goats.

The above is indicative that the nutritional properties of forages consumed by goats are transferred to milk and in turn to dairy products such as cheese, positively changing the FA composition in terms of PUFA (Serrapica et al., 2020). The same pattern was observed by Dauber et al. (2021), for FA in milk and cheese from goats supplemented with chia seeds, further confirming that these FA are stable during cheese manufacture.

There were interactions between treatment and time with some FA related to human health ($p<0.05$), among which acid caprylic (C8:0), C10:0, C18:1 *c*9, and C18:3 stand out. In the case of C8:0 and C10:0, the interaction was similar with a slight increase at the end of the experimental period, being

Table 5. *Fatty acid profile (g/100 g of total FA) of cheese from local goats in housed and grazing systems*

Fatty acid	Treatments		SEM	*P*-Value		
	Housed	Grazing		Treat	Time	Treat*time
C6:0	2.971	2.752	0.024	0.105	0.007	0.049
C8:0	3.725[a]	3.291[b]	0.045	0.017	0.013	0.076
C10:0	13.808[a]	10.870[b]	0.120	0.009	0.008	0.027
C11:0	0.462[a]	0.401[b]	0.012	0.038	0.043	0.081
C12:0	6.509[a]	4.425[b]	0.023	<0.001	0.002	0.002
C13:0	0.233[a]	0.200[b]	0.005	0.045	0.053	0.057
C14:0	12.522[a]	10.883[b]	0.029	<0.001	<0.001	0.006
C14:1	0.122	0.113	0.001	0.111	0.017	0.023
C15:0	1.113[b]	1.363[a]	0.003	0.009	0.658	0.003
C16:0	30.129[a]	27.939[b]	0.009	0.009	0.002	0.004
C16:1	0.944	0.941	0.001	0.304	0.152	0.089
C17:0	0.889[b]	1.218[a]	0.007	0.005	0.001	0.005
C17:1	0.271[b]	0.364[a]	0.012	0.014	0.001	0.335
C18:0	6.752[b]	9.079[a]	0.020	<0.001	<0.001	0.002
C18:1 *t*9	0.841[b]	1.628[a]	0.005	<0.001	0.001	0.002
C18:1 *c*9	15.271[b]	20.357[a]	0.098	0.002	<0.001	0.006
C18:2 *c*9, *c*12	1.691[a]	1.448[b]	0.011	0.004	0.004	0.053
C18:2 *c9, t*11 CLA[1]	0.184[b]	0.445[a]	0.009	0.002	0.025	0.269
C18:3	0.308[b]	0.474[a]	0.004	0.001	<0.001	0.006
C20:0	0.191[b]	0.348[a]	0.010	0.002	0.320	0.125
C20:4	0.102	0.094	0.003	0.280	0.218	0.193
Total UN	0.947[b]	1.372[a]	0.013	0.011	0.114	0.118
Total SFA[2]	79.302[a]	72.764[b]	0.093	0.002	<0.001	0.005
Total MUFA[3]	17.450[b]	23.415[a]	0.096	0.001	<0.001	0.003
Total PUFA[4]	2.284[b]	2.464 [a]	0.016	0.006	0.007	0.007
Σ <C16:0	41.455[a]	34.132[b]	0.152	0.002	0.002	0.037
Σ C16:0 + C16:1	31.018[a]	28.859[b]	0.057	0.007	0.004	0.007
Σ >C16	26.643[b]	35.579[a]	0.088	0.002	<0.001	0.004

[ab]Different letters between columns indicate a difference ($p<0.05$). SEM - standard error of the mean. UN - Unidentified, [1]CLA - Conjugated linoleic acid; [2]SFA - sum of saturated fatty acids; [3]MUFA - sum of monounsaturated fatty acids; [4]PUFA - sum of polyunsaturated fatty acids.

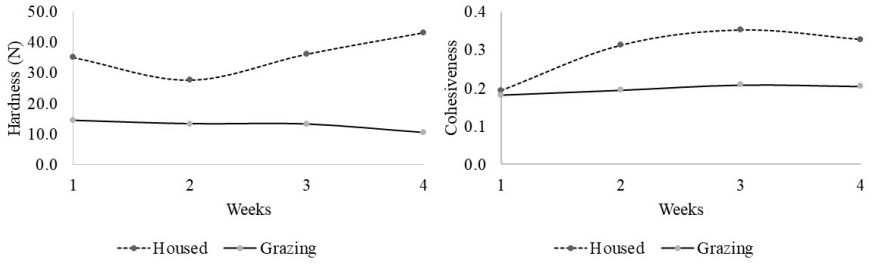

Figure 5. *Hardness and cohesiveness of local goat cheeses in housed and grazing systems during the 4-week experimental period (weekly measurements, weeks 1-4).*

higher in milk from goats in housed. Meanwhile C18:1 *c*9, and C18:3, decreased except for C18:3, which had a slight increase at the end of the experiment, with higher concentration in milk from goats in grazing.

The analysis of texture profile (ATP) of the cheese was different between treatments ($p<0.05$) (Table 5). In the case of hardness, it was lower for cheeses from grazing goats ($p<0.05$), with respect to those from housed goats. This decrease is attributed to the type of forage that influences the composition of milk FAs, which plays a key role in cheese texture (Martin et al., 2005; Coppa et al., 2011). Pasture lipids have a higher proportion of unsaturated FA which have a lower melting point than saturated FA, producing a more fluid fat and consequently softer cheeses with less hardness (Serrapica et al., 2020). In this regard, Coppa et al. (2011) found a lower hardness in cheeses from grass-fed cows compared to concentrate-fed cows, arguing the relationship between C16:0 and C18:1 *cis*-9 acids, which are the main saturated and unsaturated FA in milk that have high and low melting points, respectively.

The ratio of palmitic acid/oleic acid has been closely positively related to cheese hardness (Martin et al., 2005). The increased hardness in the cheeses from housed goats in this study can be attributed to the significantly higher concentration of palmitic acid, which has a higher melting point than UFA, resulting in a more solid fat at room temperature. In fact, palmitic acid correlates significantly and positively with hardness and chewiness attributes (O'Callaghan et al., 2017). This same behavior was found by Rangel-Ortega et al. (2024), who, in addition, argued that a high protein content is an indicator of hardness, which coincides with what was found in this research for protein content in milk.

Chewiness had the same behavior as for hardness ($p<0.05$), which is consistent, since both variables are closely related positively. Therefore, greater hardness corresponds to greater chewiness. This response agrees with the results obtained by Rangel-Ortega et al. (2024), who obtained similar values for cheeses from housed goats (9.92 N).

The cohesiveness and elasticity were higher for cheeses from goats in a housed system ($p<0.05$) with respect to those from grazing. This result is attributed to the acidity of the cheese which influences the pH. When the pH turns out to be lower than the isoelectric point (4.4-5.7), caseins acquire a negative charge, repelling protein aggregates. This leads to a greater water absorption capacity in the cheese, resulting in greater elasticity (Rangel-Ortega et al., 2024). As elasticity increases, the resistance to deformation of the cheese increases due to the flexibility of the internal bonds, thus increasing the cohesiveness of cheeses from housed goats (Martin et al., 2005). Adhesiveness showed no significant differences between treatments ($p>0.05$).

The hardness and cohesiveness of cheese from local goats in a housed and grazing system, over time, are shown in Figure 5. The hardness of cheese from housed goats showed a slight increase at the end of the experimental period ($p<0.05$) and the cohesiveness followed a similar trend throughout the experiment. In this regard, O'Callaghan et al. (2017) reported that palmitic acid correlates significantly and positively with hardness attributes due to a higher melting point than UFA, resulting in a more solid fat.

It is relevant to state that this study is limited by a small sample size, which reduces statistical power and generalizability, potentially missing longer-term trends, and a lack of testing for seasonal effects, which could obscure important cyclical variations. These limitations mean that the findings may not be representative or robust and could be influenced by specific time-of-year factors, necessitating future research with a larger sample and a longer follow-up period to capture these effects, which is the aim of our research team to work on.

Table 6. *Texture profile analysis of cheese from local housed and grazing goats*

Texture parameter	Treatments		SEM	*P*-Value		
	Housed	Grazing		Treat	Time	Treat*time
Hardness (N)	35.466[a]	12.921[b]	2.310	0.017	0.137	0.031
Adhesiveness (N*s)	-0.109	-0.132	0.008	0.210	0.015	0.396
Cohesiveness	0.296[a]	0.196[b]	0.004	0.006	<0.001	0.001
Elasticity	0.751[a]	0.575[b]	0.015	0.019	0.014	0.882
Chewyness (N)	9.874[a]	1.492[b]	0.997	0.022	0.317	0.307

[ab]*Different letters between columns indicate a difference ($p<0.05$). SEM - standard error of the mean*

Study limitations and future research

This study has some limitations that should be considered when interpreting the results. First, the experiment was conducted with a relatively small number of local "Criollo" goats from a single herd, which may limit the generalization of our findings to other breeds or production systems. Second, the experimental period covered only four weeks at the beginning of lactation, so the long-term effects of the feeding systems across the entire lactation remain unknown. Third, the grazing conditions and botanical composition of the native rangeland are specific to the semi-arid environment and season of the Comarca Lagunera, and may differ from those in other regions. In addition, we did not directly measure feed intake and nutrient digestibility, nor did we assess rumen fermentation parameters or the sensory and consumer acceptance of the cheeses, which restricts our ability to fully explain the underlying mechanisms and to link compositional changes to perceived product quality. Future studies including larger herds, different breeds, longer experimental periods and a more detailed characterization of intake, rumen metabolism, sensory attributes and economic performance would help to confirm and extend the present findings.

Conclusions

The extensive grazing production system offers benefits with respect to the nutritional quality of the cheese, exhibiting significantly higher conjugated linoleic acid and milk fat, although with a negative effect on milk production. There is a negative effect of grazing on milk protein content, cheese composition, and yield too. Local goats in arid and semi-arid zones, particularly with high rates of marginalization, are key solutions and a viable alternative to improve productivity in a sustainable manner, where the milk and cheese produced by hand are the added value that can increase the productive potential of the system, and thus strengthen the local economy. By linking product quality to husbandry practices and breed resources, the research provides an evidence base for reinforcing traditional cheese making as a driver of economic resilience, cultural continuity, and agro ecosystem sustainability in northern Mexico.

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Utjecaj sustava hranidbe na prinos, kemijski sastav i profil masnih kiselina sira proizvedenog od mlijeka lokalnih koza u sjevernom Meksiku

Sažetak

Cilj ovoga istraživanja bio je utvrditi prinos, teksturalna svojstva i kvalitetu kozjeg sira proizvedenog u zatvorenom sustavu držanja i u sustavu ekstenzivne ispaše u sjevernom Meksiku. Za proizvodnju sira korišteno je mlijeko deset odraslih lokalnih koza na početku laktacije, prosječne tjelesne mase 42±2,25 kg i s prosječno 2,5 jarenja, koje su nasumično raspoređene u dva tretmana (zatvoreni sustav, n = 5; ispaša, n = 5). Nakon 14-dnevnog razdoblja prilagodbe, koze su tijekom 28 dana muzene ručno. Procijenjeni su prinos mlijeka i sira, teksturalna svojstva te kemijski sastav sira (udio masti, proteina, vlage, soli i ukupne suhe tvari), kao i profil masnih kiselina. Statistička analiza provedena je kao dizajn s ponovljenim mjerenjima primjenom MIXED postupka. Profil masnih kiselina analiziran je jednofaktorskom analizom varijance (ANOVA) u okviru GLM postupka, a usporedba srednjih vrijednosti provedena je Tukey testom ($p<0,05$). Između tretmana utvrđene su statistički značajne razlike. U zatvorenom sustavu zabilježene su više vrijednosti ($p<0,05$) prinosa mlijeka i sira, udjela masti (22,281 %), proteina (20,173 %), ukupne suhe tvari (45,162 %), soli (0,966 %), zasićenih masnih kiselina ($p<0,001$) te analiziranih teksturnih parametara ($p<0,05$). U pašnom sustavu utvrđeno je povećanje udjela konjugirane linolne ($p<0,001$), cis-10-heptadekanske ($p=0,001$), heptadekanske ($p=0,001$), oleinske ($p<0,001$), elaidinske ($p<0,001$) i α-linolenske kiseline ($p<0,001$). Zaključno, ekstenzivni sustav ispaše pokazuje povoljniji učinak na nutritivnu kvalitetu sira, osobito glede sadržaja konjugirane linolne kiseline i sastava mliječne masti, iako uz smanjenje proizvodnje mlijeka. Povezivanjem kvalitete proizvoda s uzgojnim praksama i genetskim resursima lokalnih pasmina, ovo istraživanje pruža znanstveno utemeljenu osnovu za jačanje tradicionalne proizvodnje sira kao čimbenika ekonomske otpornosti, očuvanja kulturnog identiteta i održivosti agroekosustava u sjevernom Meksiku.

Ključne riječi: konjugirana linolna kiselina; mast; lokalne pasmine; teksturni profil; prinos

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