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RESEARCH ARTICLE

Effect of the feeding system (grazing vs. zero grazing) on the production, composition, and fatty acid profile in milk of creole goats in northern Mexico

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ABSTRACT

The objective was to compare the productive performance, composition, and fatty acid profile of the milk of creole goats under a grazing system or in zero grazing. Fourteen creole adult goats were used, randomly distributed in two homogeneous treatments (grazing, n = 7; zero grazing, n = 7). The goats had an adaptation period of 14 d, and a 49 d experimental period. Milk production and its chemical composition were analyzed in a repeated measures design. The fatty acid profile of the milk, the chemical composition of the feed, and of the plants consumed by the goats were analyzed by analysis of variance.They were manually milked once a day between 0600 to 0700 h daily. Milk production was measured individually with a portable scale. The quality (protein, fat, and lactose) was measured through infrared spectrophotometry and the fatty acid (FA) profile was obtained through gas chromatography. Differences were found ($p<0.05$) between the treatments for production, fat, protein, and lactose yield. The main milk FAs in both systems were C6:0, C14:0, C18:1n-9, C16:0 and C18: 0. A higher content of saturated FAs was found in the milk of the zero grazing ($p<0.05$) and a higher content of unsaturated FAs in the milk of grazing goats ($p<0.05$). The milk fat of grazing goats had 43% higher concentration of the 9-cis, 11-trans isomer of conjugated linoleic acid compared to milk fat from zero grazing goats. The milk of grazing goats is concluded to have a more attractive lipid profile for the consumer, with a higher concentration of compounds with potential beneficial effects on human health.

Keywords: Lipid metabolism; Functional foods; Added value.

INTRODUCTION

In Mexico, during 2020, 163,648 L^{-1} of goat's milk were produced, of which the region known as Comarca Lagunera, located in the states of Coahuila and Durango, in the north of the country, contributed 35.55% (58,178 L^{-1}; SIAP, 2021), it being the region with the highest production of goat milk in Mexico.

In this region, there are two production systems: extensive grazing and zero grazing. The extensive grazing system consists of grazing goats on ejido lands during the day, without supplementation, and at night they are enclosed to rest and for protection. The diet consists of native herbaceous, grass, and shrub species such as mesquite (*Prosopis* spp.) and Huizache (*Acacia* spp.), as well as some crop residues (Maldonado-Jáquez et al., 2017). Additionally, they have reproductive and production seasonality (Torres-Hernández et al., 2021). The goats used in this production system are called creole or native (Montaldo et al., 2010). On the other hand, in the zero grazing, the goats are completely under confinement and the feeding is based on the use of balanced diets according to the physiological state of the goat. Specialized breeds such as Saanen, French Alpine, and Toggenburg are used (Schettino-Bermúdez et al., 2018).

The main products in both production systems are kids and milk, which are different in composition and nutritional quality depending on the production system under which they were obtained. In this regard, the nutrition and feeding

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of goats influences the production and composition of milk, especially the composition of the fatty acid profile (Castillo-Miter et al., 2016; Vieitez, et al., 2016). Thus, the importance of knowing the structure and content of fatty acids (FA) in goat's milk lies in the fact that the conformation of small sizes of fat globules allows better digestibility, and the content of saturated FAs such as caprylic and capric acids which have the metabolic quality of limiting cholesterol deposits in body tissues. Similarly, regarding the content of some FAs, conjugated linoleic acid (CLA) is one of the most important, since various findings confirm positive effects on the reduction of cancer cells, coronary heart disease, and antidiabetic properties (Gómez-Cortes et al., 2019), and it has been documented that CLA is present in greater quantity in the milk of goats fed in pasture than in that of stabled goats (Tudisco et al., 2014). However, this will differ depending on the type of plant forage that the goats consume.

In goat milk, the conjugate linoleic acid (CLA) content was significantly affected by lipid supplementation and its interaction with forage levels (Martínez-Marín et al., 2011). Comparisons of grazing and zero grazing farming system characterized by grazing and a reduced amount of conserved forage generally show a higher proportion of nutritionally favourable FA such as PUFA n3, rumenic acid and CLA (Collomb et al., 2008; Malissiova et al., 2015; Tsiplakou et al., 2010). Diets rich in starch or a decrease in F/C ratio and neutral detergent fibre (NDF) content promote the growth of amylolytic and go to detriment of cellulolytic bacteria with a consequent reduction of CLA in milk fat (Vlaeminck et al., 2006).

In Mexico, studies focused on this topic are limited to a characterization of the lipid profile of goat's milk in the stabled system in the state of Guanajuato (Schettino-Bermúdez et al., 2018). In the case of goats in extensive grazing, reports have only been found in the state of Baja California (Toyes-Vargas et al., 2013a). In contrast, in the Lagunera region, as far as we know, there are no studies of this type, in particular, on creole goat breeds, despite being an important element in the economy and culture of different marginalized social groups in arid and semi-arid areas of the world (García-Bonilla et al., 2018). In the northern region of Mexico, creole goats have a well-developed market, focused on milk production, contributing to improve the quality of life of small-scale producers, so research aimed at improving nutritional quality and giving added value to milk are necessary to generate high quality foodstuffs at competitive prices, where there is a growing demand from the artisan cheese industry, which is mostly small-scale (Granados-Rivera et al., 2020). Given the aforementioned, the objective of this study was to determine the effect of the production system on the productive performance, composition, and fatty acid profile from creole goat milk in the Comarca Lagunera located in northern Mexico.

MATERIALS AND METHODS

The study was carried out in a production unit located in the Zaragoza ejido, Viesca, Coahuila, within the Comarca Lagunera. This region is located at 24° N and 104° W, at 1,100 m above sea level. The climate is desert, semi-warm with cool winters; mean annual temperature in the shade of 25 °C and mean annual rainfall of 240 mm (García, 2004).

From a commercial farm (n = 125), 14 creole adult goats were selected, with an average weight of 34.6 ± 2.25 kg, 150 ± 7.8 days (d) lactation length, and 2.5 parity. Goats were distributed equally and randomly into two treatments. The goats had a 14 d adaptation period, and 49 d experimental period. The treatments were: extensive grazing system (n = 7) and zero grazing (n = 7) (Fig. 1). In the grazing system, the goats traveled from 5 to 10 km d^{-1} during the feeding route and consumed plant species such as huizache (*Acacia* spp.), Mesquite (*Prosopis laevigata*), greasewood (*Larrea tridentata*), agave inflorescence (*Agave* spp), and alkali sacaton (*Sporobolus airoides*), in addition to agricultural residues such as melon (*Cucumis melo*) and oats (*Avena sativa*), without nutritional supplementation. In the zero grazing, the goats were housed in individual 2 x 3 m pens, provided with shade, feeding troughs, and drinking troughs with water *ad libitum*. 2.1 kg $goat^{-1}$ d^{-1} DM of an integral feed, designed according to the requirements for dairy goats proposed by the National Research Council of the United States (NRC, 2007) (Table 1), was offered. The diet was supplied in two offerings per day (0800 and 1500 h).

The goats were milked once a day manually between 0600 to 0700 h. Milk production was measured individually with a portable scale (Torrey®, capacity 10 kg ± 1 g) once a week for seven weeks (experimental period). The correction of milk production to 4% fat was made according to NRC (2001), by using the formula: FCM 4% (kg day-1) = 0.4 x milk (kg day-1) + 15 x fat (kg day-1).

The milk quality was evaluated with a sample (100 ml) of the individual production. The sample was taken in the

Fig 1. Creole goats from grazing (A) and zero grazing system.

Table 1: Ingredients and content of the integral diet prepared for goats zero grazing conditions in northern Mexico.

Ingredients	(g kg $^{-1}$ DM)
Sorghum grain	171
Maize kernels	171
Wheat bran	90
Soybean flour	90
Urea	12
Molasses	48
Vitamins and minerals[1]	18
Corn stubble	80
Alfalfa hay	320
Chemical composition	**(g kg^{-1} DM)**
Dry Matter	862
Organic matter	937
Crude protein.	141
Ethereal extract	102
Neutral detergent fibre	354
Acid detergent fibre	313

[1]Premix of minerals and vitamins (Ca 24%, P 3%, Mg 2%, Na 8%, Cl 12%, K 0.50%, S 0.50%, and antioxidant 0.50% Cl; lasolacid 2000 ppm, Cr 5 ppm, Mn 4000 ppm, Fe 2000 pp, Zn 5000 ppm, I 100 ppm, Se 30 ppm, and Co 60 ppm; vitamin A 500,000 IU, vitamin D 150,000 IU, vitamin E 1000 IU. [b]Calculated according to NRC (2007).

middle of the milking routine and it was transferred to the dairy laboratory of the INIFAP - La Laguna Experimental Campus for compositional analysis using the Milkoscope Expert Automatic® equipment (Razgrad, Bulgaria) for fat, protein, and lactose contents were determined.

The chemical compositions of the diet and of the plant species consumed by grazing goats (Table 2) were determined. These included dry matter (DM), organic matter (OM), crude protein (CP), ethereal extract (EE) (AOAC, 2006), acid detergent fiber (ADF) and the contents of NDF were analyzed with heat-stable α-amylase as suggested by Van Soest et al. (1991) and corrected for ash content.

Milk production and chemical composition were measured weekly. While chemical compositions of the diet and of the plant species consumed by grazing goats, the lipid profile of milk fat was measured once, at the end of the experiment period.

The fatty acid profiles of the diet (Table 3) and of the goat's milk (Table 4) were determined. The FA extraction was carried out according to the methodology by Feng et al. (2004), using the methylation technique by Palmquist and Jenkins (2003) and Jenkins (2010). The FA methyl esters were determined with a Hewlett Packard 6890 autosampler chromatograph with a silica capillary column (100 m x 0.25 mm x 0.20 μm thick, Sp-2560, Supelco). The identification of the FAs was done by comparing the retention times of each peak obtained from the chromatogram, with a standard of 37 components of

Table 2: Chemical composition (g kg^{-1} DM) of the integral feeds and the main plant species consumed by creole goats in northern Mexico.

	DM	OM	CP	EE	NDF	ADF
Acacia spp	901	958	112	91	481	376
Prosopis laevigata	829	902	144	81	253	382
Larrea tridentata	908	954	123	135	401	525
Agave spp	735	912	106	49	102	157
Sporobolus airoides	898	909	72	37	661	487

Table 3: Fatty acid profile (g/100 g FA) of the integral feed and plant species consumed by goats.

Fatty acid	Integral Feed	*Acacia ssp.*	*Prosopis laevigata*	*Larrea tridentata*	*Agave spp.*
<C16:0	2.21	2.28	3.72	9.16	1.30
C16:0	24.14	30.16	24.34	19.28	16.75
C16:1	1.47	4.08	2.41	ND	3.33
C17:0	ND	ND	0.91	ND	2.10
C: 18:0	2.72	9.19	9.18	3.52	1.50
C18:1 n-9	15.83	4.51	3.95	9.54	5.18
C18:2 n-6	18.66	16.74	15.21	12.39	10.92
C18:3 n-3	31.98	22.04	35.75	22.27	39.47
C20:0	0.68	2.39	2.54	1.65	1.58
C20:1	ND	ND	ND	ND	8.69
C20:4	ND	5.93	ND	ND	ND
C22:0	ND	ND	ND	2.30	1.72
C23:0	ND	2.11	ND	11.37	4.12
C24:0	ND	ND	ND	6.20	1.18
Unidentified	2.31	2.68	1.99	2.32	2.16

ND=Not detected.

FA methyl esters, and a specific standard for *cis*-9, *trans*-11 and *trans*-10, *cis*-12 isomers (Nu-Check, Elysian, Minnesota, USA).

The statistical analyses were performed with the SAS v.9.4 statistical package. For the milk production and composition data, a repeated measures design was used, with the MIXED procedure. Initial milk production was included as a covariate. The Schwartz and Akaike Bayesian information criteria were used to determine the most suitable covariance structure for each variable. The comparison of least squares means was done through the adjusted Tukey test. The information on the fatty acid profile was done using a one-way ANOVA with the GLM procedure and the comparison of means was performed with the Tukey test.

RESULTS AND DISCUSSION

Table 5 shows the results for milk production and composition by production system. Goats in the zero grazing had a higher milk production than did grazing goats ($p<0.05$). Regarding milk production in the zero grazing, our results (1.22 kg d^{-1}) were lower than other studies on stabled goats in Mexico (López et al., 2019;

Schettino-Bermúdez et al., 2018; Castillo-Miter et al., 2016). This could be due to the fact that the goats in our study were in late lactation, while in the aforementioned studies they used goats in early lactation. Additionally, they used specialized breeds, and the protein in the diets was between 17.4 and 19.2 %, which is higher than the protein content of the diet in the present study. On the other hand, the milk production of grazing goats is within the range reported for goats under grazing in the Laguna region (0.672-2.095 L d^{-1}; Salinas-González et al., 2015).

Table 4: Fatty acid profile (g 100 g^{-1} of total FA) of milk from creole grazing goats compared to zero grazing goats.

Fatty acid	Grazing	Zero grazing	SEM	*P*-Value
C4:0	1.39	1.79	0.02	0.04
C6:0	2.18	2.19	0.12	0.18
C8:0	3.12	2.66	0.03	0.01
C10:0	9.48	10.59	0.21	0.03
C11:0	0.37	0.39	0.05	0.38
C12:0	4.23	4.36	0.07	0.05
C13:0	0.24	0.21	0.03	0.08
C14:0	10.51	11.16	0.09	0.02
C14:1	0.50	0.64	0.11	0.09
C15:0	1.37	1.34	0.42	0.27
C16:0	26.75	28.56	0.19	<0.001
C16:1	1.18	1.12	0.22	0.06
C17:0	1.11	1.18	0.08	0.05
C17:1	0.47	0.46	0.06	0.08
C18:0	7.54	8.42	0.31	0.01
C18:1 *c*9	22.97	19.55	0.05	<0.001
18:2 *c*9, *c*2	3.58	2.89	0.04	0.04
C18:2 *c*9, *t*11CLA[1]	1.95	1.11	0.02	0.01
C18:3	0.40	0.30	0.09	0.16
C20:0	0.29	0.45	0.06	0.06
C20:4	0.37	0.63	0.01	0.03
<C16:0	33.39	35.34	0.15	<0.001
C16:0+C16:1	27.90	29.70	0.21	<0.001
>C16	38.71	34.96	0.31	<0.001
Total SFA[2]	68.58	73.30	0.29	<0.001
Total MUFA[3]	25.12	21.77	0.18	<0.001
Total PUFA[4]	6.3	4.93	0.08	<0.001

[1]CLA=Conjugated linoleic acid; [2]Total SFA: sum of saturated fatty acids (C4:0 to 20:0); [3]Total MUFA: sum of monounsaturated fatty acids (14:1 to 18:1); [4]Total PUFA: sum of polyunsaturated fatty acids (18:2 to 20:4).

Regarding the chemical composition of the milk, no differences were found (p>0.05) in the fat and protein content. However, there were differences on time (p<0.05) (Fig. 2). On the other hand, the performance of milk components (fat, protein, and lactose) was higher in zero grazing goats. In this regard, the percentage of fat was similar to that reported by Maldonado-Jáquez et al. (2017) for the grazing system (4.12%) and Salinas-González et al. (2015) for the zero grazing (4.59%). Regarding the protein yield, it was higher in the milk of zero grazing goats, which is similar to other reports of studies in the same region (Maldonado-Jáquez et al., 2017) and higher to reports of studies with Alpine-French goats (Castillo-Miter et al., 2016) and Saanen and Toggenburg goats (Schettino-Bermúdez et al., 2018). Regarding the yield of lactose content, which was higher in zero grazing goats, it is interesting, because said dairy component has a low variation for effect of diet; its change is mainly attributed to the race (Rooke et al., 2010). In this study, the difference in the concentration of lactose between treatments could be due to differences in the nutritional status of goats between the experimental groups. Goats that are chronically undernourished may have low lactose content in milk (Celi et al., 2008). This is an important aspect because it highlights the importance of feeding supplementation in goats with a grazing feeding system.

Table 4 shows the FA content and composition of milk by production system. The FAs found in the highest concentration in both treatments were C6:0, C14:0, C18:1n-9, C16:0, and C18:0; which represented 77.25% of the total FAs in milk from grazing goats and 78.28% of milk from zero grazing goats; which is a characteristic composition of this species (Clark and Mora, 2017). Likewise, these results coincide with those reported in studies carried out in Mexico

Table 5: Milk production and composition of creole grazing goats compared to zero grazing goats.

Variables	Feeding		SEM	*P*-Value		
	Grazing	Zero grazing		Trat	Time	Trat*Time
Milk production (kg d^{-1})	0.71[b]	1.22[a]	0.10	0.02	0.54	0.06
Corrected milk production (4% fat kg d^{-1})	0.76[b]	1.26[a]		0.01	0.62	0.08
Milk composition (g kg^{-1})						
Fat	44.31	41.82	3.64	0.17	<0.01	0.28
Protein	30.90	31.21	2.89	0.11	<0.01	0.95
Lactose	45.91[b]	47.65[a]	3.51	0.04	<0.01	0.16
Milk yield (g d^{-1})						
Fat	31.68[b]	51.08[a]	2.68	0.03	<0.01	0.09
Protein	22.07[b]	38.62[a]	1.83	0.02	<0.01	0.26
Lactose	32.69[b]	58.34[a]	2.44	0.01	<0.01	0.11

[ab]Different letters between columns indicate a difference (p<0.05).

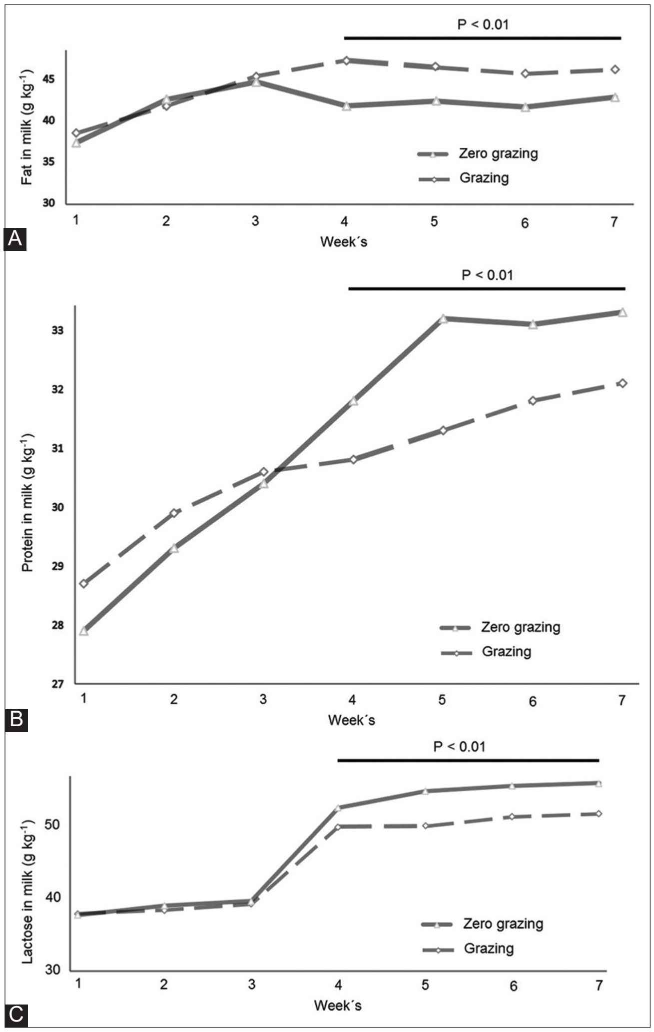

Fig 2. Weekly variation in fat (A), protein (B) and lactose (C) concentration in milk from creole goats fed with a grazing or zero grazing. *P* <.01 indicates difference on the time.

with grazing goats (Toyes-Vargas et al., 2013b) and stabled goats (Schettino-Bermúdez et al., 2018).

On the other hand, the proportion of FAs as a total percentage was 68.58% of saturated FAs, 25.12% of monounsaturated FAs and 6.3% of PUFA in the system under grazing, while for the zero grazing goats this proportion changed, 73.33% was for saturated FAs, 21.77% for monounsaturated FAs and 6.3% for polyunsaturated FAs. In this sense, the fact that milk contains a higher proportion of saturated FAs, compared to mono and polyunsaturated FAs is due to the microbial biohydrogenation process of the rumen (Marin et al., 2010).

There was a higher quantity of saturated FAs (butyric, capric, lauric, myristic, palmitic, and heptadecanoic; p<0.05) in the zero grazing. On the contrary, there were no differences between treatments for C6:0, C8:0, C11:0, C13:0, C15:0, C17:0, C18:0, and C20:0.

Regarding the content of C4:0 and C10:0, the higher amount found in the milk of zero grazing goats could be due to the fact that their diet contained a greater amount of energy and easily fermented protein, which generates a greater production of volatile fatty acids VFA, precursors of the synthesis of new FAs (Mendoza-Martínez et al., 2008). Likewise, our results agree with the studies by Schettino-Bermúdez et al. (2018) and Vieitez et al. (2016). On the other hand, it should be noted that C10:0 is important for human health, since it has been detected that it inhibits bacterial and viral growth; in addition, it does not contribute to the formation of adipose tissue. On the contrary, it dissolves serum cholesterol deposits (Markiewicz-Kęszycka et al., 2013).

The content of C12:0 in the zero grazing group is similar to that reported by D'urso et al. (2008); however, higher values (6.0 and 6.3%) have been reported in grazing goats (Toyes -Vargas et al., 2013a) and stabled goats (Schettino-Bermúdez et al., 2018; Yurchenko et al., 2018). In this regard, said performance may be affected by racial factors, environmental conditions, or physiological stages of the goat, which can alter metabolic processes and generate increases in the formation of new FAs due to the action of lipoproteins that allow the mobilization of fat from adipose tissue. This causes a greater availability of long-chain FAs that can be hydrogenated and contribute to the *de novo* synthesis of FAs (Chilliard et al., 2003). Excessive amounts of C12:0 are harmful to human health, since it can increase the concentration of low-density lipoproteins LDL in the blood, which can cause an increase in serum cholesterol (Markiewicz-Kęszycka et al., 2013).

On the other hand, regarding myristic and palmitic fatty acids, Schettino-Bermúdez et al. (2018) report values close to those obtained in this study. Meanwhile, studies carried out by Lorenzana et al. (2016) report lower values in both FAs. The differences in the concentration of these FAs in milk from grazing goats compared to milk from zero grazing goats in our study may be due to the difference in the amount of energy in the diets consumed by each group of goats (Granados-Rivera et al., 2020), favoring the synthesis of these FA in the group of zero grazing goats.

Regarding the content of monounsaturated FAs, C18:1-n-9 was significantly higher in the grazing system. While FAs such as myristoleic, palmitoleic, cis-10-heptadecenoic and elaidic did not show differences between treatments. Similarly, polyunsaturated FAs such as C18:2, C18:3, n-3 and C18:2 9-cis, 11-trans were different between treatments (p<0.05); the highest contents were found in the grazing group. In this regard, the performance of C18:2 was similar to that reported by Tudisco et al. (2014), while

Schettino-Bermúdez et al. (2018) found lower values in both production systems. Furthermore, they report lower values when the effect of the time of year on grazing goats was evaluated.

In this sense, feeding based on forages results in higher concentrations of polyunsaturated FAs because the lipid composition of these forages is usually high, especially in C18:2 and C18:3 (Toyes-Vargas et al., 2013b). These FAs cannot be synthesized in the mammary gland and for this reason they must be supplied through the diet. This is confirmed by our results, since the zero grazing goats had the lowest values, and in our study, the main effect was the type of feeding (grazing vs zero grazing).

Regarding the content of C18:3, D'urso et al. (2008) and Schettino-Bermúdez et al. (2018) indicate differences in the content of this FA between production systems and between seasons of the year. The aforementioned indicates that the content of linolenic acid is variable, since the amount present in milk fat depends on the type of feed that is supplied to the animal; however, it has been found that C18:3 can be increased by adding oleaginous seeds or vegetable oils in the diet (Chilliard et al., 2003). This is because their high content of long-chain polyunsaturated fatty acids generates a rapid transition to milk fat after their consumption (Kompan and Komprej, 2012). On the other hand, this fatty acid is important as a precursor of vaccenic acid, which finally gives rise through endogenous synthesis to conjugated linoleic acid (CLA) isomer 9-*cis*, 11-*trans* (Granados-Rivera and Hernández-Mendo, 2018).

In this sense, conjugated linoleic acid CLA 9-*cis*, 11-*trans* is part of the unsaturated fatty acids and differences were evidenced in the lipid profile of goat milk between production systems. The higher concentration was found in milk from grazing goats, as pointed out by Castillo-Miter et al. (2016) and as can be seen in the content of this FA in zero grazing goats (Schettino-Bermúdez, 2018; Vieitez et al., 2016). Finally, the concentrations of this FA vary according to the type of food and the composition of fatty acids that it contains; however, an adequate proportion of linoleic FA and linolenic FA could increase the production of CLA 9-*cis*, 11-*trans* (D'urso et al., 2008). It is important due to the potential beneficial effects on health such as the reduction of fat mass and direct incidence on heart disease, antiatherogenic, lipid-lowering, antidiabetic, and immunomodulatory properties, among others (Gómez-Cortes et al., 2019).

CONCLUSIONS

It is concluded that the production system influences the productive level of the animals, as well as the performance of the milk components and the fatty acid profile, but does not modify the fat and protein composition of milk.

On the other hand, goat's milk obtained in extensive grazing has a lower amount of saturated fatty acids and a higher amount of unsaturated fatty acids; aspect that positions it as a food with functional qualities. This can be used to benefit small-scale producers who keep goats in extensive systems, by offering a product with added value, which can help increase the sale price of milk.

Authors' Contributions

Lorenzo Danilo Granados-Rivera Conceptualization, Methodology, Formal analysis, Investigation, Resources, Writing - Original Draft, Writing, Review and Editing, Visualization and Supervision.

Jorge Alonso Maldonado-Jáquez Conceptualization, Methodology, Formal analysis, Investigation and Resources.

Pablo Alfredo Domínguez-Martínez Supervision, Writing - review and editing.

Jaime Salinas-Chavira Supervision, Writing - review and editing.

Yuridia Bautista-Martínez Conceptualization, Methodology, Formal analysis, Investigation, Supervision, Writing review and editing.

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