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Growth performance, rumen development, and sensorial meat quality of goat kids fed extruded and pelleted starters

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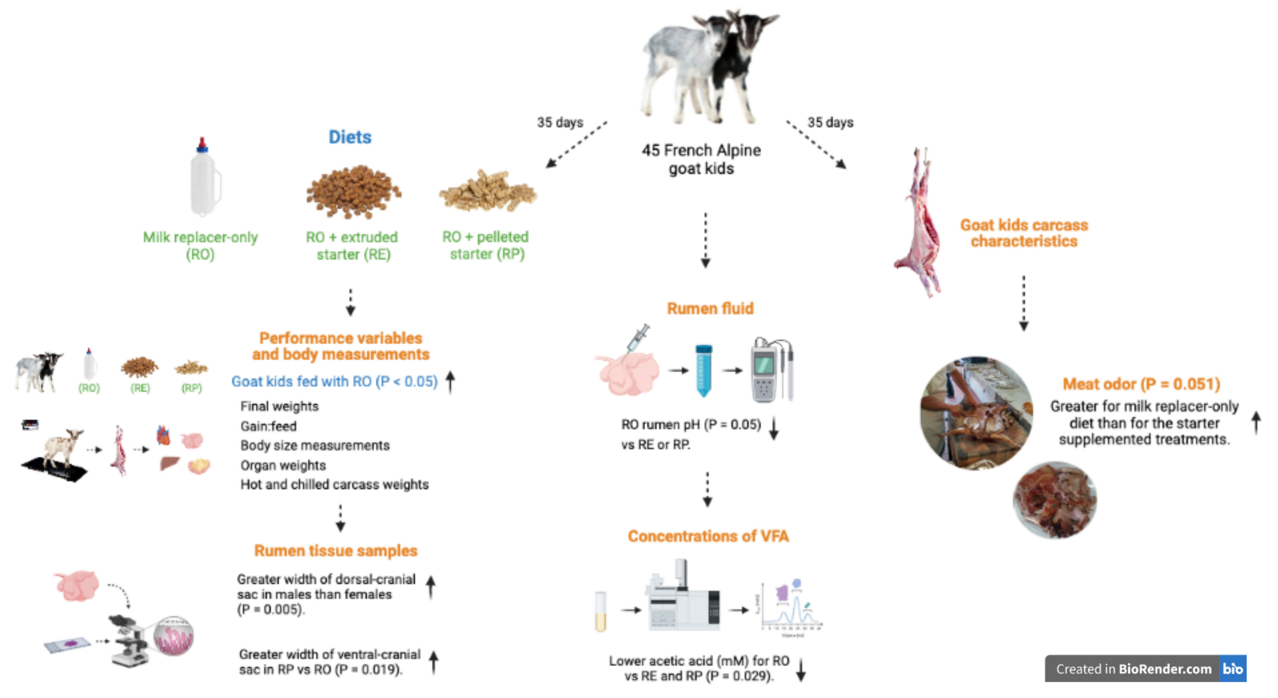
The aim of this study was to determine the effects of supplementing extruded and pelleted starter feeds on growth performance, rumen development, carcass characteristics, and sensorial meat quality of goat kids fed an all-milk protein replacer. Forty-five new-born French Alpine kids (21 males, 4.93 $\pm$ 0.58 kg; and 24 females, 4.40 $\pm$ 0.60 kg) were randomly assigned to three treatment diets, milk replacer-only (RO), milk replacer supplemented with extruded starter feed (RE), or milk replacer supplemented with pelleted starter feed (RP) in a 3 x 2 factorial arrangement. After 35 days, the final weights, weight gain, body size measurements, organ weights, and hot and cold carcass weights were greater ($p < 0.05$) for goat kids in the RO group compared to those in the RE and RP groups. Milk replacer intake was reduced ($p = 0.000$) with starter supplementation, and intake of the extruded starter was higher ($p = 0.001$) than that of the pelleted starter. The rumen weight was greater ($p = 0.019$) in the RE group than in the RO group. Rumen pH was higher ($p = 0.006$) and acetic acid ($p = 0.008$) and total VFA ($p = 0.012$) concentrations were lower in the RO group than in the RE and RP groups. Mesenteric fat content was higher ($p = 0.002$) in the RO group than in the other groups. Meat odor of the RO group was preferred ($p = 0.051$) by the sensorial panel. Feeding an RO diet is beneficial for goat kids sold to restaurants. For replacement kids, an extruded starter feed may improve rumen development and facilitate adaptation to post-weaning dry feed consumption.

KEYWORDS

carcass characteristics, extruded starter feed, goat kids, meat quality, rumen development



GRAPHICAL ABSTRACT

1 Introduction

Goat kid meat is a popular dish in several regions of Mexico and other countries. Goat kids are usually fed only milk, but several feeding strategies can be developed by studying the development and function of the rumen epithelium (Wang et al., 2009). Different factors affect the speed of rumen development, including the type of diet and production management (Jiao et al., 2015). Early introduction of solid feeds can be important to accelerate rumen development and facilitate early weaning of ruminants. The presence and absorption of volatile fatty acids (VFA) stimulate rumen epithelial metabolism and are key in initiating rumen epithelial development (Diao et al., 2019).

The addition of concentrates to the diet accelerates rumen development, which is directly related to VFA production from fermentation of forage and concentrates in the rumen (Suárez et al., 2006; Wang et al., 2009). Forage in the diet is minimal in the early stages of life because it is associated with reduced dry matter (DM) intake and reduced rumen fermentation. In contrast, high-grain concentrate feeds are widely used since they lead to increased DM intake and provide high concentrations of VFA required for optimum rumen papillae development (Nocek et al., 1980; Coverdale et al., 2004; Suárez et al., 2007).

Worldwide, cereal grains are used as main sources of starch. Mechanical and chemical alterations during steam flaking or extrusion of grains can increase the surface area of exposure, thereby enhancing starch fermentation, VFA production, and rumen development (Murphy et al., 1994; Huntington, 1997). Solid feeds that exclude forage or roughage can influence rumen capacity compared to finely grounded or pelleted diets, suggesting that the extent of processing and particle size affects the ability of concentrates to stimulate rumen development. Therefore, concentrate diets with large particle sizes appear favorable for rumen development due to their ability to stimulate rumen epithelium development and rumen capacity (Greenwood et al., 1997; Beharka et al., 1998).

Extrusion is one of the most common methods of hydrothermal treatment used in the production of pet food, fish feed, and some horse feeds. This process converts feed into granule-shaped compound feeds, which are then dried, coated, and cooled. Extrusion increases the nutrient utilization of feeds by gelatinizing starch from cereal grains, thereby enhancing their energy utilization (Feed Manufacturing Technology, 2005). This process increases the amount of protein reaching the small intestine and enhances the absorption of amino acids from the feed. Extruded feeds with gelatinized starch and high fat levels are energy-dense and resistant to breakage (Berends et al., 2018).

The hypothesis of this research was that supplementing goat kids an extruded starter feed, in addition to a milk replacer, will improve their carcass weight and meat quality. The objective of this study was to supplement goat kids, fed an all-milk protein replacer and intended for restaurants, with extruded or a pelleted starter feed and to determine the effects of this supplementation on growth, performance, rumen development, carcass characteristics, and sensorial meat quality.

2 Materials and methods

2.1 Animals, diets, and sampling procedures

This study was conducted in compliance with the current Mexican legislation (NOM-033-ZOO-2014) and approved by the Internal Committee for Animal Welfare in Teaching and Research at the Faculty of Veterinary Medicine, University of Nuevo León.

Forty-five French Alpine goat kids (21 males, 4.93 ± 0.58 kg, and 24 females, 4.40 ± 0.60 kg) aged less than 1 week were randomly assigned to one of three diets according to a 3 x 2 factorial design (three diets and two sexes). Dietary treatments were: (1) milk replacer-only (RO), (2) milk replacer and extruded starter (RE), and (3) milk replacer and pelleted starter (RP). The goat kids were transferred to individual pens with feeders and water troughs. Water was offered *ad libitum*. The goat kids received colostrum for the first 2 days after birth and were then adapted to milk replacer and starter feeds. The kids on RO diet were initially offered 250 mL milk replacer twice daily at 8:00 and 15:00 the first week and were *ad libitum* fed the following weeks. Kids on the RE and RP diets were initially offered 250 mL of milk replacer twice daily at 8:00 and 15:00 during the first week and 500 mL at 8:00 in the following weeks. In these groups, the extruded and pelleted starters were offered *ad libitum* after the first week.

The composition of the commercial all-milk protein replacer was 24.6% crude protein, 20.7% fat, 0.13% crude fiber, and 5.1% ash. The composition of the extruded and pelleted starter feeds (REWS®; MNA de México, Monterrey, México) is presented in Table 1. Ingredient composition included ground corn, soybean meal, corn gluten meal, wheat middling, palm oil, salt, mineral-vitamin premix, monocalcium phosphate, calcium carbonate, *Saccharomyces cerevisiae* yeast culture, and methionine hydroxy-analog (hydroxy-methyl butyric acid). Sodium lignosulphonate and molasses were used for pellet compaction.

TABLE 1 Replacer feed composition (g/kg) and chemical analysis.

Feed ingredients (as fed basis)	Pelleted	Extruded
Corn	345	384
Soybean meal	375	380
Corn gluten meal	75	75
Wheat middling	80	80
Molasses	40	—
Palm oil	50	50
Sodium lignosulfonate	4	—
Calcium carbonate	8.5	8.5
Monocalcium phosphate	5	5
Sodium chloride	10	10
Saccharomyces cerevisiae yeast culture	5	5
Methionine hydroxy-analogue	2	2
*Mineral-vitamin premix	0.5	0.5
Chemical analysis		
Metabolizable energy (Mcal/kg)	3.18	3.19
Crude protein (%)	26.8	26.9
Crude fat (%)	7.7	8.4
Ash-free neutral detergent fiber (%)	11.4	11.8
Crude fiber (%)	4.4	4.5
Ash (%)	7.5	9.2

*Mineral-vitamin premix: Mn, 44,000 mg/kg; Cu 20,000 mg/kg; I, 1,200 mg/kg; Co, 660 mg/kg; Se, 400 mg/kg; vitamin A, 4,400,000 IU/kg.

2.2 Milk replacer and starter feed analysis

Weekly composite samples of starter feed and orts were dried in an air-draft oven at 60°C and ground through a 1 mm screen in a Thomas Model 4 Willey® Mill (Thomas Scientific, Swedesboro, NJ, USA) before analysis. Moisture content was determined (Method 925.45; Procedure 1960) by drying in an air-draft oven at 105°C (AOAC, 1997). Ash content (Method 942.05) was determined after simple combustion in a muffle furnace at 600°C for 3 h. The ether extract (Method 920.39) was analyzed using the Soxhlet method (AOAC, 1997). To determine crude protein (CP) concentration, the micro-Kjeldahl method (Method 920.176) was used (AOAC, 1997), with CP calculated as N × 6.25. Crude fiber and neutral detergent fiber (NDF) were analyzed using the Ankom 200 fiber analyzer. The ash-free NDF (NDFom) content was determined as indicated by Uden et al. (2005), and metabolizable energy was calculated using values reported for ingredients by the National Research Council.

2.3 Growth, body measurements, and carcass characteristics

Dry matter (DM) intake (g/d) and daily weight gain (g/d) were measured. DM intake was obtained from milk replacer and starter feed intakes. Initially, 100 g of starter feed was offered, and this amount was increased daily by 10% of the previous day's intake. The kid's fasting weight was recorded at 8:00 on days 1 and 36 of the experiment to calculate average daily weight gain (ADG). Offered and rejected starter feed were recorded daily. Feed efficiency was calculated as gain:feed.

At the end of the experiment (day 36), height to the shoulder, body length, and chest circumference of all goat kids were measured before transporting them to the slaughterhouse, where the final weight was obtained. After slaughter, hot carcass weight and dressing percent (carcass weight as percent of shrunk live weight) were recorded. The carcasses were hung and refrigerated for 24 h at 4°C, and cold carcass weight was obtained. Cold carcasses were used to determine pH in the right side of the *longissimus dorsi* muscle using a portable Hanna® pH meter. Meat color values were measured with a Minolta® color meter (L*, luminosity or light intensity; a*, tendency for red color; and b*, tendency for yellow color) after 5 min of meat exposure to oxygen. Fresh weights of organs (skin, head, heart, liver, and small intestine), stomach compartments (reticulum, rumen, omasum, and abomasum) without digesta, and total and empty gastrointestinal tract (GIT) were obtained.

2.4 Rumen development measurements

The height and width of rumen papillae (µm) were measured. For histological evaluation, rumen wall tissue samples from the dorsal-caudal sac, dorsal-cranial sac, ventral-cranial sac, and ventral-caudal cecum were processed as described by Lesmeister et al. (2004). Formaldehyde-fixed tissues samples were paraffin-embedded, sectioned at 4 µm and stained with hematoxylin and eosin. Papillae height was defined as the distance between the base to the top of the papillae, and papillae width was defined as the average width of the diameter of the base, middle, and top sections of the papillae. Measurements were obtained using a ZEISS microscope with a digital image processing program ImageJ.

2.5 Rumen fluid measurements

Rumen fluid was obtained using a stomach tube 2 h postprandial. Ruminal pH was measured immediately after sampling using a pH meter (Denver Instruments). One mL of HCl was then added to rumen fluid samples to stop fermentation, followed by centrifugation at 10,000 *g* for 10 min. The samples were stored at -20°C. For VFA analysis, the rumen fluid samples were thawed, and 6 mL were centrifuged at 5,000 rpm for 20 min at 4°C. Then, 5 mL of the supernatant was mixed with 1 mL of 25% (w/v) metaphosphoric acid containing 2 g of 2-butyric acid as internal standard and centrifuged at 10,000 *g* for 10 min. The supernatant fraction was analyzed to determine the VFA concentration using a Varian Star 3400 CX gas chromatograph (Goetsch and Galyean, 1983). The control samples (rumen fluid + buffer) were processed in the same manner. Concentrations (mM) of acetate, propionate, butyrate, and total VFA (sum of the three) were determined after adjusting the VFA concentration using the control samples.

2.6 Sensorial quality of meat

A consumer trial was conducted in a local restaurant that sells charcoal roasted goat kid meat, organized by the Sensorial Food Evaluation Laboratory of the University of Nuevo León to determine the differences in the sensorial aspects of meat obtained from the differently treated kids. A total of ten trained panelists participated in the sensory evaluation. Each panelist evaluated the sensory attributes of meat from three female and three male kids per treatment. The goat kid carcasses were roasted by the restaurant personnel using their established cooking and temperature techniques. Goat kid carcasses were cooked in a grill for roasting meat, at a distance of 50 cm from the heat source, until reaching an internal temperature of 70°C, a process that took 3 h. Meat samples were cut into pieces measuring 1.5 cm × 1.5 cm, placed on a plate with an identification code, covered with aluminum foil, and maintained at 60°C until serving. Meat attribute (odor, flavor, juiciness, and tenderness) was evaluated using a 5-point hedonic scale, where 5 = liked much and 1 = disliked much (Meilgaard et al., 2006).

2.7 Statistical analysis

The data were analyzed using a completely randomized design with a 3 × 2 factorial arrangement of treatments, employing the statistical program Statistix® (Analytical Software; Tallahassee, Florida, USA). The Tukey test was used for multiple comparisons, considering $p < 0.05$ to determine statistical significance between the treatment means. A two-sample t-test was performed to determine the differences in starter DM intake between goat kids fed the extruded and pelleted starter feeds. The sensory attributes were analyzed using an ANOVA considering in the statistical model the effect of sex (δ_i), treatment (T_j), and their interaction $\delta T_{(ij)k}$; the evaluator was considered as a block effect (B_l). The $\delta T_{(ij)k}$ and δ_i were not significant ($p > 0.05$) for sensory attributes. In the case of fixed effects, with $p < 0.05$, the Tukey test was performed to compare the means; and with $0.05 < p > 0.10$, it was considered a tendency.

3 Results

3.1 Performance, body measurements, and organ weights

At the end of the 35-day experiment, the RO group had greater final weights ($p = 0.023$) and daily weight gains ($p = 0.006$) than the RE and RP groups (Table 2). Weight gains were 84.9, 51.5, and 43.0 kg for the RO, RE, and RP groups, respectively. Goat kids on RO consumed more ($p < 0.001$) daily milk replacer DM (104.7 g/d) than the other groups (RE, 54.3 g/d; RP, 52.2 g/d). Although starter DM intake was greater ($p = 0.032$) in the RE group (51.9 g/d) than in the RP group (32.1 g/d), total DM intake was not different ($p > 0.05$) between the groups.

At the end of the study, height to the shoulder was not different ($p > 0.05$) between the groups (Table 3); the males were taller (47.5 cm; $p < 0.001$) than females (43.7 cm). Chest circumferences were greater ($p < 0.01$) in the RO group than in the RE and RP groups. Goat kids on the RO diet had greater liver ($p = 0.015$) and heart ($p = 0.001$) weights than those on the other diets. Additionally, male kids had greater liver ($p = 0.002$) and small intestine ($p = 0.023$) weights than female kids (Table 3).

3.2 Rumen development and fermentation

Reticulum-rumen weights were greater in the RE groups ($p = 0.026$) than in the RO and RP groups, but when separated from the reticulum, the rumen weight was greater for the RE group ($p =$

TABLE 2 Performance variables of goat kids fed milk replacer-only, or additionally supplemented extruded or pelleted starters.

Variable	Diet[1]			SEM[2]	Sex[1]		SEM[2]	P-value[1]		
	RO	RE	RP		M	F		D	S	D x S
Final weight (kg)	7.55[a]	6.45[ab]	6.04[b]	0.512	7.47[a]	5.89[b]	0.420	0.023	0.001	0.985
Weight gain (g/d)	84.9[a]	51.5[b]	43.0[b]	12.30	76.3[a]	43.3[b]	10.09	0.006	0.003	0.860
Dry matter intake (g/d)										
Milk replacer	104.7[a]	54.3[b]	52.2[b]	6.28	76.6[a]	64.1[b]	5.16	0.001	0.022	0.217
Starter feed[3]	–	51.9[a]	32.1[b]	9.10	35.2	20.8	7.49	–	–	–
Total intake	104.7	104.1	86.3	10.79	111.8[a]	84.9[b]	8.86	0.169	0.005	0.913
Gain:feed (g/g)	0.78[a]	0.46[b]	0.46[b]	0.080	0.65[a]	0.49[b]	0.066	0.001	0.019	0.848

[1]RO, milk replacer-only; RE, milk replacer and an extruded starter; RP, milk replacer and a pelleted starter; M, male; F, female; D, diet; S, sex; D x S, and diet and sex interaction.
[2] SEM, standard error of the mean.
[3] Contrasts: RE compared with RP (P = 0.032).
[ab] Means in the same row with different superscripts are statistically different (P < 0.05).

0.019) than the RO group, but not different from the RP group (Table 4). The rumen papillae width of the dorsal-cranial sac was greater (p = 0.005) in males (932 µm) than in females (597 µm), with no difference (p > 0.05) between the diet groups. In the ventral-cranial sac of the rumen, greater (p = 0.019) papillae width measurements were reported in the RP group (915 µm) than in the RO group (590 µm) (Table 5).

Rumen fluid pH was higher (p = 0.006) in the RO group (3.59) than in the other groups (RE, 2.97; RP, 2.61). Acetic acid concentration (mM) of the rumen fluid was lower (p = 0.008) in the RO group than in the RE or RP groups (Table 6). Additionally, the total volatile fatty acid concentration of the rumen fluid was lower (p = 0.012) for RO (8.30 mM) than for RE (13.93 mM) and RP (15.40 mM). When expressed as molar percentages, the proportions of acetic, propionic, and butyric acids were not different (p > 0.10) between the treatment groups (Table 6).

3.3 Carcass characteristics and meat quality

Goat kids on the RO diet had heavier hot (p = 0.014) and cold (p = 0.011) carcass weights than the RE and RP groups, with males having heavier weights (p ≤ 0.001) than females (Table 7). The weight of mesenteric fat was greater (p = 0.002) in the RO group (0.05 kg) than in the RE (0.02 kg) and RP (0.02 kg) groups, with no significant difference (p > 0.05) between males and females.

The interaction effect of sex and starter did not affect the sensory acceptability of the sensory attributes of goat meat (Table 7). For fixed effects, only the treatment affected (p < 0.05) the odor of the goat meat, and a tendency (0.05 < p > 0.10) was observed for flavor and juiciness. Sex showed a significant tendency (p = 0.058) for flavor, with the most accepted meat being from RO and the least accepted from RP.

TABLE 3 Body size and organ weights of goat kids fed milk replacer-only, or additionally supplemented extruded or pelleted starters.

Variable	Diet[1]			SEM[2]	Sex[1]		SEM[2]	P-value[1]		
	RO	RE	RP		M	F		D	S	D x S
Body size (cm)										
Height to the shoulder	45.6	44.2	44.3	1.282	46.7[a]	42.7[b]	1.056	0.515	< 0.001	0.847
Chest circumference	46.7[a]	43.6[b]	43.1[b]	1.079	46.4[a]	42.5[b]	0.889	0.007	< 0.001	0.686
Femoral tuberosities length	15.7[a]	13.6[b]	13.4[b]	0.421	15.0[a]	13.5[b]	0.347	0.000	< 0.001	0.561
Humeral tuberosities length	14.0[a]	11.9[b]	11.7[b]	0.459	13.1[a]	11.9[b]	0.378	0.000	0.005	0.306
Organ weight (kg)										
Liver	0.25[a]	0.19[b]	0.20[b]	0.020	0.24[a]	0.18[b]	0.017	0.015	0.002	0.731
Heart	0.08[a]	0.06[ab]	0.04[b]	0.008	0.06	0.05	0.007	0.001	0.194	0.424
Small intestine	0.24	0.27	0.23	0.038	0.29[a]	0.21[b]	0.031	0.445	0.023	0.422
Head	0.54	0.53	0.52	0.036	0.56[a]	0.50[b]	0.029	0.797	0.047	0.449
Skin	1.40	1.29	1.26	0.112	1.39	1.25	0.093	0.451	0.137	0.769

[1]RO, milk replacer-only; RE, milk replacer and an extruded starter; RP, milk replacer and a pelleted starter; M, male; F, female; D, diet; S, sex; D x S, and diet and sex interaction.
[2] SEM, standard error of the mean.
[ab] Means in the same row with different superscripts are statistically different (P < 0.05).

TABLE 4 Total gastrointestinal tract (GIT) and stomach compartment weights of goat kids fed milk replacer-only, or additionally supplemented extruded or pelleted starters.

Variable (kg)	Diet[1]			SEM[2]	Sex[1]		SEM[2]	P-value[1]		
	RO	RE	RP		M	F		D	S	D x S
GIT	1.86	1.94	1.74	0.183	2.05[a]	1.65[b]	0.149	0.513	0.012	0.266
Empty GIT	0.32	0.27	0.26	0.037	0.30	0.28	0.031	0.202	0.559	0.755
Omasum-abomasum	0.107	0.086	0.091	0.018	0.01	0.01	0.015	0.516	0.918	0.873
Rumen-reticulum	0.08[b]	0.12[a]	0.11[ab]	0.016	0.11	0.09	0.013	0.026	0.139	0.130
Rumen	0.06[b]	0.10[a]	0.09[ab]	0.014	0.10	0.77	0.011	0.019	0.137	0.112
Reticulum	0.01	0.02	0.02	0.002	0.02	0.02	0.002	0.363	0.346	0.169

[1]RO, milk replacer-only; RE, milk replacer and an extruded starter; RP, milk replacer and a pelleted starter; M, male; F, female; D, diet; S, sex; D x S, and diet and sex interaction.
[2] SEM, standard error of the mean.
[ab] Means in the same row with different superscripts are statistically different (P < 0.05).

The odor of the meat was more accepted for RO, while RE obtained less preference (Table 7). This same trend was observed for meat flavor. However, in terms of juiciness, RO improved acceptability, whereas RE decreased meat preference. Meat color variables did not differ among the treatment groups or between females and males (Table 8).

4 Discussion

4.1 Performance, body measurements, and organ weights

During the first week of life, goat kids eat very little of the starter feed, but by the third week, they should rapidly increase their consumption (Goetsch et al., 2001; Genandoy et al., 2002). In the present study, goat kids separated from their dams two days after consuming colostrum were fed an all-milk protein replacer as a sole diet or supplemented with extruded or pelleted starter feeds. Milk replacer DM intake was 92.8% and 100% lower in goat kids in the extruded and pelleted starter groups, respectively. Starter intake was 61.7% greater with extruded starter than with pelleted starter. Other studies (Rahman et al., 2016; Zobel et al., 2020) reported no significant difference in milk or milk replacer and starter feed intakes of goat kids.

Final weights, daily weight gains, gain:feed, body size measurements, and organ weights were greater for goat kids fed the RO diet compared to those fed RE or RP diets. Amaral et al. (2005) reported a greater DM intake and daily weight gain in goat kids receiving a pelleted ration compared to ground or extruded rations that contained 40% hay and only 29.3% ground corn. The starch level in these feeds was too low and fiber level was too high, making them unsuitable for extrusion. The best extrusion results and rumen development can be obtained with a high-starch starter

TABLE 5 Papillae length and width in four sections of the rumen of goat kids fed milk replacer-only, or additionally supplemented extruded or pelleted starters.

Variable	Diet[1]			SEM[2]	Sex[1]		SEM[2]	P-value[1]		
	RO	RE	RP		M	F		D	S	D x S
Papillae length (μm)										
Caudal-dorsal sac	1373	1950	1713	318	1833	1524	268	0.256	0.256	0.467
Dorsal-cranial sac	1264	1897	1804	266	1607	1703	225	0.098	0.671	0.324
Ventral-cranial sac	1793	2309	2099	334	2049	2086	266	0.330	0.891	0.169
Ventral-caudal blind sac	1801	2155	2254	368	2147	1993	311	0.536	0.622	0.098
Papillae width (μm)										
Caudal-dorsal sac	566	784	742	114	664	731	122	0.267	0.585	0.122
Dorsal-cranial sac	747	693	793	82	879[a]	609[b]	89	0.317	0.005	0.023
Ventral-cranial sac	516[b]	804[ab]	937[a]	116	703	801	124	0.019	0.435	0.376
Ventral-caudal blind sac	655	850	779	133	760	762	140	0.425	0.990	0.430

[1]RO, milk replacer-only; RE, milk replacer and an extruded starter; RP, milk replacer and a pelleted starter; M, male; F, female; D, diet; S, sex; D x S, and diet and sex interaction.
[2] SEM, standard error of the mean.
[ab] Means in the same row with different superscripts are statistically different (P < 0.05).

TABLE 6 Volatile fatty acids (VFA) in rumen fluid of goat kids fed milk replacer-only, or additionally supplemented extruded or pelleted starters.

Variable	Diet[1]			SEM[2]	Sex[1]		SEM[2]	P-value[1]		
	RO	RE	RP		M	F		D	S	D x S
Rumen pH	3.59[a]	2.80[b]	2.65[b]	0.280	3.05	2.97	0.230	0.006	0.713	0.728
VFA (mM)										
Acetic acid	7.45[b]	14.04[a]	13.65[a]	2.111	11.58	11.84	1.730	0.008	0.883	0.844
Propionic acid	0.41	0.72	0.53	0.402	0.50	0.61	0.330	0.747	0.748	0.616
Butyric acid	0.23	0.43	0.64	0.250	0.42	0.44	0.204	0.293	0.951	0.179
VFA (molar %)										
Acetic acid	93.64	93.92	91.53	2.845	92.64	93.42	2.331	0.653	0.743	0.526
Propionic acid	3.83	3.96	3.88	2.033	4.01	3.77	1.665	0.998	0.885	0.541
Butyric acid	2.53	2.13	4.60	1.420	3.35	1.163	1.375	0.184	0.652	0.189
Total VFA	8.09[b]	15.18[a]	14.82[a]	2.386	12.51	12.88	1.955	0.012	0.849	0.722

[1]RO, milk replacer-only; RE, milk replacer and an extruded starter; RP, milk replacer and a pelleted starter; M, male; F, female; D, diet; S, sex; D x S, and diet and sex interaction.
[2] SEM, standard error of the mean.
[ab] Means in the same row with different superscripts are statistically different (P < 0.05).

feed by altering the rate of ruminal fermentation and the rate of digesta passage, thereby affecting solid feed intake (Amaral et al., 2005).

Goat kids on the RO diet had greater body measurements than those supplemented with extruded or pelleted starters. The growth rate and overall health of pre-weaned goat kids can be significantly influenced by their diet. Very young goat kids have a digestive system that is initially more suited to digesting milk or milk replacer than solid food because their rumen is not fully developed. Another factor involved is nutrient concentration; increased intake of a high-energy, nutrient-rich food source support more rapid growth (Abdelsattar et al., 2023). Castro and Elizondo (2012) reported that calves supplemented with a pelleted or extruded replacer had greater height than those not supplemented. This can be attributed to the provision of nutrients for rumen fermentation and to a more metabolically and physically developed reticulum-rumen (Khan et al., 2007).

The liver and heart weights of goat kids on the RO diet were heavier than those of kids on RE and RP diets, and males had heavier head weights than females. Perez et al. (2001) reported no differences in liver or heart weights of goat kids supplemented with 1 L/d of goat milk, goat milk replacer, or calf milk replacer, although the kids fed goat milk had greater head and skin weights that those fed the replacers. Vacca et al. (2014) reported no significant

TABLE 7 Carcass characteristics, mesenteric fat, and meat pH of goat kids fed milk replacer-only, or additionally supplemented extruded or pelleted starters.

Variable	Diet[1]			SEM[2]	Sex[1]		SEM[2]	P-value[1]		
	RO	RE	RP		M	F		D	S	D x S
Hot carcass weight (kg)	4.02[a]	3.26[b]	3.11[b]	0.295	3.97[a]	2.96[b]	0.243	0.014	< 0.001	0.985
Cold carcass weight (kg)	3.85[a]	2.98[b]	2.99[b]	0.295	3.71[a]	2.84[b]	0.243	0.011	0.001	0.796
Hot carcass dressing (%)	52.9	50.96	51.69	2.005	52.98	50.71	1.652	0.644	0.179	0.912
Cold carcass dressing (%)	50.7	47.22	49.57	2.543	49.66	48.64	2.095	0.395	0.628	0.567
Mesenteric fat (kg)	0.05[a]	0.02[b]	0.02[b]	0.007	0.03	0.03	0.006	0.002	0.645	0.924
Meat pH	5.87	5.79	6.15	0.055	5.83	6.04	0.045	0.525	0.689	0.390
Meat characteristics										
Juiciness	3.73	3.37	3.48	0.126	3.5	3.56	0.103	0.111	0.702	0.994
Odor	3.97[a]	3.7[ab]	3.57[b]	0.117	3.77	3.72	0.096	0.051	0.743	0.973
Flavor	3.78	3.75	3.45	0.131	3.53	3.79	0.107	0.145	0.094	0.515
Tenderness	3.87	3.7	3.77	0.138	3.76	3.80	0.138	0.692	0.781	0.692

[1]RO, milk replacer-only; RE, milk replacer and an extruded starter; RP, milk replacer and a pelleted starter; M, male; F, female; D, diet; S, sex; D x S, and diet and sex interaction.
[2] SEM, standard error of the mean.
[ab] Means in the same row with different superscripts are statistically different (P < 0.05).

TABLE 8 Color variables of goat kid meat from kids fed milk replacer-only, or additionally supplemented extruded or pelleted starters.

Variable[4]	Diet[1]			SEM[2]	Sex[1]		SEM[2]	P-value[1]		
	RO	RE	RP		M	F		D	S	D x S
L*	48.58	49.10	52.50	2.239	50.35	49.77	1.833	0.19	0.757	0.942
a*	11.93	11.84	12.23	1.234	12.75	11.24	1.010	0.946	0.152	0.556
b*	7.76	7.97	8.50	0.841	8.31	7.83	0.689	0.667	0.493	0.369
Color	33.18	33.65	35.17	1.717	33.24	34.77	1.406	0.492	0.29	0.333

[1]RO, milk replacer-only; RE, milk replacer and an extruded starter; RP, milk replacer and a pelleted starter; M, male; F, female; D, diet; S, sex; D x S, and diet and sex interaction.
[2] SEM, standard error of the mean.
L*, luminosity or light intensity; a*, tendency for red color; and b*, tendency for yellow color.

difference in the heart, lung, liver, or head weights between goat kids suckling their dams twice daily and those supplemented with acidified milk replacer *ad libitum*.

4.2 Rumen development and fermentation

In this study, rumen weights of goat kids supplemented with the RE diet were significantly greater than those of kids consuming the RO diet. As goat kids grow, they continuously increase their consumption of solid feed, allowing the rumen to develop and microorganisms to thrive. Amaral et al. (2005) fed *ad libitum* meals and pelleted and extruded starters to goat kids; they observed that the reticulum-rumen weights of the kids fed the pelleted and extruded starters were heavier than those of the kids fed the meal starter. Kristensen et al. (2007) reported that starter intake led to an increase in the reticulum-rumen size of calves as opposed to milk replacer, owing to an increase in blood concentrations of volatile fatty acids. In another study of calves (Pazoki et al., 2017) fed a starter feed prepared with different manufacturing processes, the reticulum-rumen size was greater in calves fed a meal starter feed and alfalfa hay than in those fed only pelleted or meal starters, indicating that forage improves functionality and reticulum-rumen capacity, resulting in a thick and muscular rumen wall. Castro and Elizondo (2012) did not find a significant difference in the reticulum-rumen weight of calves fed a meal starter, meal starter and forage, extruded starter, or pelleted starter.

For rumen papillae measurements, tissue samples are commonly obtained from the caudal-dorsal and/or cranial-ventral sacs, which represent rumen development as effectively as samples taken from other areas of the rumen (Lesmeister et al., 2004). The rumen epithelium is entirely lined with papillae that are the sites of absorption of fermentation acids produced within this compartment, but the size and density of papillae vary with developmental stage and with diet to a large extent (National Research Council (NRC), 2007).

Starter feeds that contain dry grain are important for successful rumen development and early weaning of goat kids. Feeding readily fermentable carbohydrates to increase VFA production can stimulate rumen development, and the particle size of grains and fiber sources in starter feeds are important in maintaining intake and rumen papillae structure (Beharka et al., 1998; Bach et al., 2007; Diao et al., 2019).

Goat kids supplemented the RP diet had a significantly lower rumen pH than those fed the RO diet. A rumen pH of 2.61 to 3.59, as observed in this study, is typically observed in underdeveloped rumens. Pazoki et al. (2017) fed calves meal, pelleted, or texturized feed and alfalfa hay, finding no difference in rumen pH between the treatment groups. Changes in the physical form of grain can have an influence on rumen functionality, intake, and digestibility. During grain thermal processing, starch is gelatinized, increasing the surface area for rumen microorganisms to bind, thus affecting VFA production and rumen pH (Diao et al., 2019).

In this study, the concentration of acetic acid was greater in goat kids fed the RE diet than in those fed the RO diet, although molar percent of acetic, propionic, and butyric acids did not differ among groups. Several authors have found no differences in rumen VFA concentrations of calves fed starter feed in different physical forms (Beharka et al., 1998; Pazoki et al., 2017). However, with age, the concentration of propionic acid increased in those fed a pelleted starter feed, suggesting increased digestion of the finely ground and pelleted starter (Pazoki et al., 2017).

4.3 Carcass characteristics and meat quality

Cabrito is the Spanish term used to describe meat from suckling goat kids, weighing less than 8 kg or 45 days of age, which are often roasted on a stick over a charcoal fire. This dish is commonly consumed by people in northern México (Sahlu et al., 1991). Carcass weights and hot and cold dressing percent were greater for goat kids on the milk replacer-only diet than for those on other diets, and these weights were also greater for males than for females. Genandoy et al. (2002) reported greater slaughter weights for goat kids fed milk *ad libitum* compared to goat kids fed limited amount of milk with *ad libitum* quantities of a starter feed. In contrast, other studies (Perez et al., 2001; Napolitano et al., 2002; Todaro et al., 2006) reported no difference in hot carcass weights between goat kids fed milk, milk replacer, and supplemented starter feed.

Goat kids fed the RO diet had more abdominal (mesenteric) fat in their carcasses than those supplemented the RE and RP diets, a characteristic appreciated by local consumers. In a previous study, goat kids that consumed whole milk had more internal fat deposition (mesenteric, kidney, and pelvic) than those who consumed limited milk and supplemental concentrate *ad libitum* (Genandoy et al., 2002; Vacca et al., 2014).

The ultimate pH is determined at 24 h after slaughter. The variation in ultimate pH (pHu) influences factors such as color and the ability of the meat to retain water. A low pHu results in meat proteins having decreased water-holding capacity and a lighter color (Webb, 2014). In our study, carcass meat pH obtained 24 h after slaughter was not different between dietary treatments, varying between 5.8 and 5.9. Webb (2014) reported that most pH values of goat meat were between 5.6 and 6.2. Argüello et al. (2005) observed no difference in meat pH of goat kids fed milk *ad libitum* or a milk replacer twice a day plus a starter feed after 15 days of age. Our results are also in agreement with those reported by Marichal et al. (2003), who obtained similar 24 h *postmortem* pH values in the meat of goat kids fed milk replacer and a pelleted starter feed. Therefore, the rumen of goat kids that consume a starter feed is adapted to the consumption of a large amount of carbohydrates, with a consequently increased glycogen in muscle. Goat carcasses with a lower pHu tend to be more tender, with lower shear force values and better colorimetric values than those with a high pHu (Webb, 2014).

Sensorial meat quality can be evaluated by its flavor, juiciness, odor, and tenderness (Zervas and Tsiplakou, 2011). The meat of goat kids has a stronger odor and flavor that can be attributed to branched chain fatty acids, particularly 4-ethyloctanoic acid (Webb, 2014). In this study, no differences were observed in the meat attributes between the treatment groups, except for the meat odor of the kids fed the RO diet, which was considered the most pleasant by the tasting panel. This aligns with the belief that the meat of goat kids fed only milk, with no dry feed in their diets, have preferable organoleptic characteristics from the consumer´s perspective. In a review by Goetsch et al. (2011), the meat of goat kids fed milk was more tender than the meat of kids fed a milk replacer, which was attributed to quick adaptation and increased DM intake.

5 Conclusion

Starter feed supplementation improved rumen development of goat kids; however, greater carcass weights were obtained for kids fed the replacer-only diet without starter supplementation. A favorable characteristic of feeding a milk replacer-only diet was the presence of abdominal fat in their carcasses, which is appreciated by local consumers. Of all carcass quality characteristics, only the meat odor of goat kids fed the replacer-only diet was preferred by the sensorial panel. However, for replacement female kids, an extruded feed starter can improve rumen development and facilitate adaptation to dry feed consumption.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: http://eprints.uanl.mx/22196/1/1080315272.pdf.

Ethics statement

The animal study was approved by Internal Committee for Animal Welfare in Teaching and Research at the Faculty of Veterinary Medicine, University of Nuevo León. The study was conducted in accordance with the local legislation and institutional requirements.

Author contributions

DR-C: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft. YR-Z: Conceptualization, Formal analysis, Methodology, Validation, Visualization, Writing – review & editing. CG-H: Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. GM-Z: Conceptualization, Data curation, Formal analysis, Methodology, Software, Validation, Writing – review & editing. HF-D: Conceptualization, Data curation, Formal analysis, Software, Validation, Writing – review & editing. GM-D: Conceptualization, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – review & editing. JK: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – review & editing.

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Conflict of interest

Authors YR-Z, CG-H, and JK were employed by MNA de México, S.A. de C.V.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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References

Abdelsattar, M. M., Zhao, W., Saleem, A. M., Kholif, A. E., Vargas-Bello-Pérez, E., and Zhang, N. (2023). Physical, metabolic, and microbial rumen development in goat kids: A review on the challenges and strategies of early weaning. *Anim. (Basel).* 13, 1–12. doi: 10.3390/ani13152420

Amaral, C., Sugohara, A., Resende, K., MaChado, M., and Cruz, C. (2005). Performance and ruminal morphologic characteristics of Saanen kids fed ground, pelleted or extruded total ration. *Small Rum. Res.* 58, 47–54. doi: 10.1016/j.smallrumres.2004.08.009

AOAC. (1997). *Official methods of analysis. 16th ed* (Washington, D. C: Association of official analytical chemists).

Argüello, A., Castro, N., Capote, J., and Solomon, M. (2005). Effects of diet and live weight at slaughter on kid meat quality. *Meat Sci.* 70, 173–179. doi: 10.1016/j.meatsci.2004.12.009

Bach, A., Giménez, A., Juaristi, J. L., and Ahedo, J. (2007). Effects of physical form of a starter for dairy replacement calves on feed intake and performance. *J. Dairy Sci.* 90, 3028–3033. doi: 10.3168/jds.2006-761

Beharka, A., Nagaraja, T., Morrill, J., Kennedy, G., and Klemm, R. (1998). Effects of form of the diet on anatomical, microbial, and fermentative development of the rumen of neonatal calves. *J. Dairy Sci.* 81, 1946–1955. doi: 10.3168/jds.S0022-0302(98)75768-6

Berends, H., Vidal, M., Terré, M., Leal, L. N., Martín, J. T., and Bach, A. (2018). Effects of fat inclusion in starter feeds for dairy calves by mixing increasing levels of a high-fat extruded pellet with a conventional highly fermentable pellet. *J. Dairy Sci.* 101, 10962–10972. doi: 10.3168/jds.2018-15116

Castro, F. P., and Elizondo, S. J. (2012). Crecimiento y desarrollo ruminal en terneros alimentados con iniciador sometido a diferentes procesos. *Mesoam. J. Agro.* 23, 343–352. doi: 10.15517/am.v23i2.6534

Coverdale, J., Tyler, H., Quigley, J., and Brumm, J. (2004). Effect of various levels of forage and form of diet on rumen development and growth in calves. *J. Dairy Sci.* 87, 2554–2562. doi: 10.3168/jds.S0022-0302(04)73380-9

Diao, Q., Zhang, R., and Fu, T. (2019). Review of strategies to promote rumen development in calves. *Animals* 9, 490–505. doi: 10.3390/ani9080490

Genandoy, H., Sahlu, T., Davis, J., Wang, R., and Hart, S. (2002). Effects of different feeding methods on growth and harvest traits of young Alpine kids. *Small Rumin. Res.* 44, 81–87. doi: 10.1016/S0921-4488(02)00039-1

Goetsch, A. L., Detweiler, G., Sahlu, T., and Dawson, L. J. (2001). Effect of different management practices on preweaning and early postweaning growth of Alpine kids. *Small Rumin. Res.* 41, 109–116. doi: 10.1016/S0921-4488(01)00207-3

Goetsch, A. L., and Galyean, M. L. (1983). Influence of feeding frequency on passages of fluid and particulate markers in steers fed a concentrate diet. *Can. J. Anim. Sci.* 63, 727–730. doi: 10.4141/cjas83-084

Goetsch, A., Merkel, R., and Gipson, T. (2011). Factors affecting goat meat production and quality. *Small Rumin. Res.* 101, 173–181. doi: 10.1016/j.smallrumres.2011.09.037

Greenwood, R., Morrill, J., Titgemeyer, E., and Kennedy, G. (1997). A new method of measuring diet abrasion and its effect on the development of the forestomach. *J. Dairy Sci.* 80, 2534–3541. doi: 10.3168/jds.S0022-0302(97)76207-6

Huntington, G. (1997). Starch utilization by ruminants: from basics to the bunk. *J. Anim. Sci.* 75, 852–867. doi: 10.2527/1997.753852x

Jiao, J., Li, X., Beauchemin, K. A., Tan, Z., Tang, S., and Zhou, C. (2015). Rumen development process in goats as affected by supplemental feeding vs. grazing: age-related anatomic development, functional achievement and microbial colonization. *Br. J. Nutr.* 113, 888–900. doi: 10.1017/S0007114514004413

Khan, M., Lee, H., Lee, W., Kim, H., Kim, S., Ki, K., et al. (2007). Starch source evaluation in calf starter: I. feed consumption, body weight gain, structural growth, and blood metabolites in Holstein calves. *J. Dairy Sci.* 90, 5259–5268. doi: 10.3168/jds.2007-0338

Kristensen, N. B., Sehested, J., Jensen, S. K., and Vestergaard, M. (2007). Effect of milk allowance on concentrate intake, ruminal environment, and ruminal development in milk-fed Holstein calves. *J. Dairy Sci.* 90, 4346–4355. doi: 10.3168/jds.2006-885

Lesmeister, K. E., Tozer, P. R., and Heinrichs, A. J. (2004). Development and analysis of a rumen tissue sampling procedure. *J. Dairy Sci.* 87, 1336–1344. doi: 10.3168/jds.S0022-0302(04)73283-X

Marichal, A., Castro, N., Capote, J., Zamorano, M., and Argüello, A. (2003). Effects of live weight at slaughter (6, 10 and 25 kg) on kid carcass and meat quality. *Livest. Prod. Sci.* 83, 247–256. doi: 10.1016/S0301-6226(03)00113-1

Meilgaard, M., Civille, G. V., and Carr, T. B. (2006). "Affective tests consumer tests and in-house panel acceptance tests," in *Sensory evaluation techniques*. Eds. M. Meilgaard, G. V. Civille and T. B. Carr (CRC Press, Boca Raton), 231–251.

Murphy, T., Fluharty, F., and Loerch, S. (1994). The influence of intake level and corn processing on digestibility and ruminal metabolism in steers fed all-concentrate diets. *J. Anim. Sci.* 72, 1608–1615. doi: 10.2527/1994.7261608x

Napolitano, F., Cifuni, G., Pacelli, C., Riviezzi, A., and Girolami, A. (2002). Effect of artificial rearing on lamb welfare and meat quality. *Meat Sci.* 60, 307–315. doi: 10.1016/S0309-1740(01)00140-1

National Research Council (NRC). (2007). *Nutrient requirements of small ruminants: sheep, goats, cervids and new world camelids*. (Washington, DC: National Research Council, National Academy of Science).

Nocek, J., Herbein, J., and Polan, C. (1980). Influence of ration physical form, ruminal degradable nitrogen and age on rumen epithelial propionate and acetate transport and some enzymatic activities. *J. Nutr.* 110, 2355–2364. doi: 10.1093/jn/110.12.2355

Pazoki, A., Ghorbani, G., Kargar, S., Sadeghi, A., Drackley, J., and Ghaffari, M. (2017). Growth performance, nutrient digestibility, ruminal fermentation, and rumen development of calves during transition from liquid to solid feed: Effects of physical form of starter feed and forage provision. *Anim. Feed Sci. Techn.* 234, 173–185. doi: 10.1016/j.anifeedsci.2017.06.004

Perez, P., Maino, M., Morales, M., and Soto, A. (2001). Effect of goat milk and milk substitutes and sex on productive parameters and carcass composition of Creole kids. *Small Rumin. Res.* 42, 87–94. doi: 10.1016/S0921-4488(01)00233-4

Rahman, M., Talukder, M., Ali, M. Y., and Akter, M. (2016). Effect of milk replacer on kid performance among small holder farmers. *Asian J. Med. Biol. Res.* 2, 357–360. doi: 10.3329/ajmbr.v2i2.29082

Sahlu, T., Carneiro, H., El Shaer, H. M., and Fernández, J. M. (1991). *Relative performance of Angora kids fed acidified milk replacer* (Langston, Oklahoma: E. de la Garza Institute for Goat Research).

Schofield, E. K. (2005). *Feed Manufacturing Technology. fifth edition* (1501 Wilson Blvd., Suite 1100 Arlington, VA 22209: American Feed Industry Association).

Suárez, B., Van Reenen, C., Gerrits, W., Stockhofe, N., Van Vuuren, A., and Dijkstra, J. (2006). Effects of supplementing concentrates differing in carbohydrate composition in veal calf diets: II. Rumen Development. *J. Dairy Sci.* 89, 4376–4386. doi: 10.3168/jds.S0022-0302(06)72484-5

Suárez, B., Van Reenen, C., Stockhofe, N., Dijkstra, J., and Gerrits, W. (2007). Effect of roughage source and roughage to concentrate ratio on animal performance and rumen development in veal calves. *J. Dairy Sci.* 90, 2390–2403. doi: 10.3168/jds.2006-524

Todaro, M., Corrao, A., Barone, C., Alicata, M., Schinelli, R., and Giaccone, P. (2006). Use of weaning concentrate in the feeding of suckling kids: Effects on meat quality. *Small Rumin. Res.* 66, 44–50. doi: 10.1016/j.smallrumres.2005.06.038

Udén, P., Robinson, P. H., and Wiseman, J. (2005). Use of detergent system terminology and criteria for submission of manuscripts on new, or revised, analytical methods as well as descriptive information on feed analysis and/or variability. *Anim. Feed Sci. Technol.* 118, 181–186.

Vacca, G., Pazzola, M., Piras, G., Pira, E., Paschino, P., and Dettori, M. (2014). The effect of cold acidified milk replacer on productive performance of suckling kids reared in an extensive farming system. *Small Rumin. Res.* 121, 161–167. doi: 10.1016/j.smallrumres.2014.08.002

Wang, Y., Xu, M., Wang, F., Yu, Z., Yao, J., Zan, L., et al. (2009). Effect of dietary starch on rumen and small intestine morphology and digesta pH in goats. *Livestock Sci.* 122, 48–52. doi: 10.1016/j.livsci.2008.07.024

Webb, E. C. (2014). Goat meat production, composition, and quality. *Anim. Front.* 4, 33–37. doi: 10.2527/af.2014-0031

Zervas, G., and Tsiplakou, E. (2011). The effect of feeding systems on the characteristics of products from small ruminants. *Small Rum. Res.* 101, 140–149. doi: 10.1016/j.smallrumres.2011.09.034

Zobel, G., Freeman, H., Watson, T., Cameron, C., and Sutherland, M. (2020). Effect of different milk removal strategies at weaning on feed intake and behavior of goat kids. *J. Anim. Behav.* 35, 62–68. doi: 10.1016/j.jveb.2019.10.004