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Rumen development and blood metabolites of Criollo kids under two different rearing systems

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This study compared rumen development and blood metabolite concentrations of Criollo kids under two different rearing systems. Forty goat kids were reared by their dams, suckling goat milk from birth until weaning at 45 (TR, traditional rearing system, $n=20$) or 30 days of age (AR, alternative rearing system, $n=20$). Goat kids in the AR group were offered a solid starter diet ad libitum from birth until 45 days of age and a growing diet (80% alfalfa hay and 20% ground corn) from 30 to 90 days of age. The TR group was fed a growing diet (without starter diet) between 30 and 90 days of age. Blood samples were analyzed for serum concentration of glucose, total protein, blood urea nitrogen (BUN), < beta > -hydroxybutyrate (< beta > HB), and non-esterified fatty acids (NEFA). Five kids from each group were slaughtered at 21, 45, 70 and 90 days of age to determine rumen variables. AR kids consumed 32.7 % less goat milk than TR kids throughout the trial. Body weight of AR kids at 45–60 days of age was lower than the traditional market weight. Rumen weight (as % of body weight) was higher ($P<0.01$) in AR kids than in TR kids at 21 and 45 days of age. Furthermore, rumen weight (as % of weight of all compartments) was higher in AR kids compared to TR kids at 21, 45 and 70 days of age. Rumen papillae of AR kids tended ($P<0.10$) to be longer than those of TR kids at 21 and 45 days of age. Blood glucose concentration decreased with increasing age of kids, indicating a shift from glucose to short-chain fatty acids as primary energy source. Serum < beta > HB and BUN concentrations at 30 and 45 days of age were higher ($P<0.05$) in AR kids than in TR kids. The higher serum concentrations of BUN and < beta > HB were attributed to early development of rumen microbial fermentation activity and to greater metabolic development of the rumen epithelium of AR kids compared to TR kids. In conclusion, the alternative rearing system improves the physical and metabolic development of the rumen and promotes the transition of kids from pre-ruminant to ruminant. In dry periods with shortage of forage, the alternative rearing system could be used, but these goat kids should be reared above the traditional age to enable them to achieve an appropriate weight for marketing.

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1. Introduction

The Criollo is the most common breed in Argentina (MAGYP, 2010). These goats descend from breeds brought to Argentina by Spaniards and Portuguese settlers from the Canary Islands, and are genetically related to a wider population distributed in the Andes region (Amills et al., 2009).

Goats are distributed in all regions and ecosystems, but are more common in dry and arid environments (Devendra, 2010). In Argentina, as in other developing countries, most goats are raised in extensive production systems on rangelands, with little or no feed and mineral supplementation to animals (Allegretti et al., 2012, Devendra, 2010). Under these conditions, the nutritional status of goats, reproductive performance and their milk and meat production are highly dependent on annual forage availability. In these pastoral systems, goat kids are reared suckling their mothers until they are slaughtered, so the milk production of goats determines the growth rate of kids (Paez Lama et al., 2013). Therefore, in severe dry years with low forage availability, not all kids reach appropriate weight and fatness for the market (Guevara et al., 2006).

In cattle production systems, early weaning has traditionally been recommended to counteract shortages in forage as a result of low rainfall (Galindo-Gonzalez et al., 2007). However, early weaning is known to have undesirable consequences on growth rate, health and welfare of animals (Morand-Fehr et al., 1982; Atasoglu et al., 2008). In the first weeks of life, the goat kids rely on nutrients obtained from their dam's milk, because the rumen is physically and metabolically underdeveloped. Rumen development is triggered by the ingestion of solid feed, the establishment of a microbial flora and the accompanying processes of rumen fermentation and absorption of volatile fatty acids by ruminal epithelium (Baldwin et al., 2004). A feeding strategy that promotes early rumen development will reduce the lag between demand and supply of nutrients after weaning, minimizing the decline in the growth rate of animals (Khan et al., 2011).

For the above reasons, in extensive goat production systems, it would be useful to develop alternative rearing systems that allow the growing of goat kids and a rapid recovering of body energy reserves of dams in years of adverse weather conditions.

Although there are many studies on the effect of early consumption of solid feed on rumen development, studies on growth and rumen development of Criollo goat kids under rearing systems different to the traditional were not found. Furthermore, the development of alternative rearing systems is important because these could be used in several countries with goat breeds and production systems similar to those of Argentina.

It was hypothesized that an alternative rearing system with early supply of solid feed will promote rumen development, allowing early weaning of goat kids without major consequences on their post-weaning growth, enabling them to achieve adequate marketing conditions. The objective of this study was to assess body weight, rumen development and blood metabolite concentrations of Criollo goat kids reared under a traditional or an alternative rearing system.

2. Materials and methods

2.1. Animals, management and treatments

All experimental procedures and animal care practices were in agreement with the provisions of the Guide for Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010). Forty single-born Criollo male kids with their respective dams were selected from the goat farm "La Majada" (32°19′39′S, 67°54′36′W). The kids were assigned to two treatments ($n=20$), balancing the groups according to their birth body weight (BW, 2.92 ± 0.31 kg). Goat kids were separated from their dams at 3 days of age and were placed in individual pens (1.5×0.75 m^2) bedded with wood shavings. Thereafter, goat kids were allowed to suckle milk from their respective dams for about 30 min twice daily at 0730 and 1930 h until weaning either at 30 (AR, alternative rearing group) or 45 days of age (TR, traditional rearing group). In addition, goat kids in the AR group were offered a commercial starter diet ad libitum from the beginning of trials until 45 days of age, and a growing diet composed of alfalfa hay and ground corn (80 % and 20 % on dry matter basis, respectively) from 30 to 90 days of age. Goat kids in the TR group did not receive the commercial starter diet but were offered the growing diet between 30 and 90 days of age. Starter diet and growing diet were provided twice daily at 0800 and 2000 h. All goat kids were raised until 90 days of age to assess growth rate and rumen development after weaning. All animals were treated for internal and external parasites with ivermectin (0.2 mg kg^{-1}) and were vaccinated against clostridial organisms. The adult goats were all in their third to sixth birth, weighed 36.5 ± 4.7 kg and had a body condition score of 2.03 ± 0.21 (scale 1–5). During nursing of kids, goats were fed 1 kg of alfalfa hay and 0.5 kg of ground corn on dry matter basis. Clean drinking water and mineral licks were always available ad libitum. The composition of mineral licks (in %, as specified by the manufacturer) was: Ca (3.12), P (0.33), Mg (2.53), S (0.17), Na (9.35), K (0.24), Zn (0.25), Cu (0.15), Se (0.01), I (0.02), and Mn (0.25). During the trial period the minimum, maximum and mean temperature registered at the pens was 14.0, 28.5 and 20.4 °C, respectively.

2.2. Sampling and analyses

The chemical composition of the kid starter diet and growing diet was determined in the Laboratory of Nutrition and Forage Quality Assessment, EEA INTA Balcarce, and milk was analyzed in the Laboratory of Food Quality, EEA INTA Salta (Table 1).

Goat kids were weighed at birth and body weight was registered weekly thereafter. Milk intake was measured twice a week by difference between the kid's body weight before and after suckling. Kid starter diet and growing diet intake were measured daily by difference between feed offered and orts. Total dry matter intake (total DMI) was calculated by adding the milk solids, kid starter diet and growing diet. Body weight, milk, kid starter, growing diet and total DMI were averaged every 15 days. Average daily

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Table 1
Composition of diets (on DM basis) offered to kids during trials.

Composition (%)	Goat milk[a]	Kid starter diet[b]	Growing diet[c]
Dry matter	12.9	92.1	90.5
Crude protein	3.9	25.8	14.1
NDF		13.5	45.6
ADF		6.1	29.5
Ether extract	3.7	8.6	2.6
Ash	0.8	5.9	9.0
ME MJ/kg[d]	2.96	17.6	8.4

[a] Milk composition expressed per kg of fresh milk.
[b] Ruter®, ACA.
[c] Composed by 80% alfalfa hay and 20% ground corn on a DM basis.
[d] Metabolizable energy (ME) of milk was estimated according to the equation: MJ/kg = 1.4694 + (0.4025 × milk fat%) (Nsahlai et al.., 2004).

gain (ADG) and feed efficiency (FE, intake/gain) were calculated.

Blood samples were collected before the morning feeding by jugular venipuncture at 15, 30, 45, 60 and 90 days of age, and were analyzed for serum concentration of glucose (glucose oxidase peroxidase enzymatic method, GT lab kit), blood urea nitrogen (BUN, Berthelot colorimetric method, GT lab kit), total protein (TP, Biuret colorimetric method, Wiener lab kit), <beta>-hydroxybutyrate (<beta>HB, Ranbut kit, Randox Laboratories Ltd.), and non-esterified fatty acids (NEFA, FA 115 kit, Randox Laboratories Ltd.).

Five kids from each group were randomly selected and slaughtered at 21, 45, 70 and 90 days of age after a 12 h fasting with free access to water. The reticulo-rumen, omasum and abomasum were dissected and individually weighed with their content. Then they were emptied, rinsed repeatedly with water, drained and reweighed. Rumen tissue samples of approximately 1 cm^2 were collected from the ventral sac according to Lesmeister et al. (2004). Rumen tissue samples were fixed in a solution of 10% formaldehyde for microscopic analysis. Slides were observed under a light microscope (Arcano XSZ 100 BNT). Digital images were obtained using a digital camera (Moticam 352), and measurements were performed using image analysis computer software (Motic image plus 2.0). Papillae height was determined by measuring the distance from the tip to the base of the papillae.

2.3. Statistical analysis

Data were statistically analyzed using the GLM procedure of InfoStat statistical software (InfoStat, 2011).

Rumen measurements were analyzed according to the following model:

$$Y_{ijk} = \mu + R_i + T_j + RT_{ij} + \epsilon_{ijk}$$

where Y_{ijk} is dependent variable, μ is overall mean, R_i is fixed effect of rearing system, T_j is fixed effect of time, RT_{ij} is treatment × time interaction effect, and ϵ_{ijk} is experimental error. When not significant, the interaction was excluded from the model.

Blood metabolites, body weight, average daily gain, milk intake, kid starter, growing diet, total DM intake and feed efficiency were analyzed with a repeated measures design according to the following model:

$$Y_{ijk} = \mu + R_i + T_j + RT_{ij} + A_k + \epsilon_{ijk}$$

where Y_{ijk} is dependent variable, μ is overall mean, R_i is fixed effect of rearing system, T_j is fixed effect of time, RT_{ij} is treatment × time interaction effect, A_k is random kid effect, and ϵ_{ijk} is experimental error. When not significant, the interaction was excluded from the model.

The covariance structure for each variable analyzed was chosen by comparing several models with different covariance structures. The covariance structure yielding the lowest AIC value (Akaike's Information Criterion) was selected (Di Rienzo et al., 2011). When effects of treatment, time or treatment × time interaction were significant, differences between means were determined by Fisher's LSD test. For all variables analyzed, significance was declared at $P < 0.05$ and tendencies at $P < 0.10$.

3. Results

Body weight, milk intake, kid starter diet intake, growing diet intake, total DMI, ADG and feed efficiency are shown in Table 2. During the first 30 days of age there was no difference in average daily milk consumption between groups of goat kids. The average goat milk production during the nursing period was 1.16 ± 0.14 and 1.15 ± 0.17 kg of fresh milk per day, for AR and TR groups, respectively. Average total milk consumption for the whole suckling period (30 and 45 days in length for AR and TR, respectively) was 4.51 ± 0.15 and 6.70 ± 0.20 kg DM per kid for AR and TR groups, respectively. Starter diet intake by AR kids was negligible during the first two weeks and very low thereafter. As expected, starter diet intake increased after weaning and was higher ($P < 0.001$) than the pre-weaning intake (Table 2). Solid feed intake (kid starter plus growing diet) by AR kids increased ($P < 0.001$) after weaning. The same occurred with solid feed intake by TR kids, in which post-weaning growing diet intake was 3.65 times greater than the pre-weaning intake. Total DMI by AR kids was lower at 30–45 days ($P < 0.001$), and higher at 45–60 and 60–75 days of age ($P < 0.001$) compared to TR kids. After 75 days of age, there were no differences in total DMI between groups. Total DMI after weaning was similar ($P > 0.05$) for both groups (18.9 ± 0.23 g per kg BW for AR kids at 30–45 days and 18.7 ± 0.59 g per kg BW for TR kids at 45–60 days). Average daily gain of AR kids was lower between 30 and 45 days of age ($P < 0.001$) and higher between 45 and 90 days of age ($P < 0.01$) compared to TR kids. The feed efficiency values of AR goat kids between 30 and 45 days of age were negative and lower ($P < 0.001$) than those of TR goat kids, whereas between 75 and 90 days of age, feed efficiency was better ($P < 0.01$) in AR goat kids than in TR goat kids.

Body weight at 30–45, 45–60 and 60–75 days of age was higher ($P < 0.001$, $P < 0.001$ and $P < 0.01$, respectively) in TR goat kids than in AR goat kids, while there were no differences between groups at 1–15, 15–30 and 75–90 days old (Table 2).

Empty rumen weight increased with age of kids ($P < 0.001$), with no differences between treatments

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Table 2
Body weight, dry matter intake, average daily gain and feed efficiency according to rearing system and age of goat kids.

Age (d)	1–15		15–30		30–45		45–60		60–75		75–90		
Rearing system	TR	AR	TR	AR	TR	AR	TR	AR	TR	AR	TR	AR	s.e.m
Body weight (kg)	3.67	3.41	6.29	5.49	7.99[a]	5.57[b]	9.04[a]	6.41[b]	9.54[a]	8.13[b]	11.82	11.65	0.2
Milk intake, g DM day^{-1}	150.1	148.7	144.5	151.7	149.3	–	–	–	–	–	–	–	4.5
Kid starter diet intake, g DM day^{-1}	–	–	–	11.5	–	27.2	–	–	–	–	–	–	1.5
Growing diet intake, g DM day^{-1}	–	–	–	–	46.4[a]	78.1[b]	169.4[a]	238.6[b]	279.4[a]	372.0[b]	468.2	474.4	5.7
Total DMI (g kg BW^{-1})	40.9	43.6	22.7	29.8	24.5[a]	18.9[b]	18.7[a]	37.2[b]	29.3[a]	45.7[b]	39.5	40.6	0.9
Average daily gain (g)	155.7	150.4	132.4	109.9	66.7[a]	−63.9[b]	66.7[a]	110.4[b]	85.5[a]	122.3[b]	158.4[a]	218.6[b]	5.94
Feed efficiency	0.92	0.93	1.06	1.49	3.03[a]	−1.81[b]	2.45	2.18	3.19	3.27	2.84[a]	1.74[b]	0.13

[a] [b]Means with different superscripts in the same row and within same age group indicate statistical differences between treatments ($P<0.05$).
TR and AR; traditional and alternative rearing systems, respectively. s.e.m; standard error of the mean.
Feed efficiency (Total DMI intake/average daily gain, g/g).

Table 3
Rumen measurements of Criollo kids under traditional and alternative rearing systems.

Age (d)	21		45		70		90		Effect[a]			
Rearing system	TR	AR	TR	AR	TR	AR	TR	AR	s.e.m	*R*	*T*	*R* × *T*
Empty rumen weight (g)	55.6	80.9	161.1	159.8	258.3	269.6	372.8	428.2	21.6	NS	***	NS
Rumen weight as % of weight of all compartments	55.5[a]	63.1[b]	61.0[a]	70.1[b]	73.5[a]	77.3[b]	73.2	74.2	1.3	***	***	NS
Rumen weight as % of BW	0.93[a]	1.47[b]	1.98[a]	3.36[b]	3.14	3.74	3.29	3.62	0.17	***	***	*
Papillae height (μm)	662	842	1376	1686	2058	2124	2726	2644	129	NS	***	NS

[a] [b]Means with different superscripts in the same row and within same age group indicate statistical differences between treatments ($P<0.05$).
TR and AR; traditional and alternative rearing systems, respectively. s.e.m; standard error of the mean.
NS not significant.
[a] Effects were treatment (*R*, rearing system), time (*T*) and rearing system × time interaction (*R* × *T*).
* $P \leq 0.05$.
*** $P \leq 0.001$.

(Table 3). However, when empty rumen weight was expressed as percentage of body weight, the rumen was heavier in AR kids than in TR kids at 21 and 45 days of age ($P<0.01$). Furthermore, rumen weight expressed as percentage of weight of all compartments was higher in AR kids at 21, 45 and 70 days of age ($P<0.01$, $P<0.05$ and $P<0.001$, respectively) compared to TR kids. Papillae height increased with age of kids ($P<0.001$) but, contrary to expectations, it was not affected by treatments. However, the papillae of AR kids tended to be longer than those of TR kids at 21 and 45 days of age ($P=0.079$, and $P=0.088$, respectively).

Blood glucose concentration decreased ($P<0.001$) with increasing age of kids for both groups (Table 4). However, no significant differences were found in serum glucose concentration between kids from both groups throughout the trial. Serum NEFA concentration was not affected by treatment, although there was an effect of age of kids. Blood <beta>HB concentration in AR kids was higher than in TR kids at 30 and 45 days of age ($P<0.05$). There were no differences between both groups at other ages. Serum BUN concentration was affected ($P<0.001$) by age of kids, and concentration of this metabolite in AR kids was higher than in TR kids at 30 and 45 days of age ($P<0.01$). The serum total protein concentration was affected ($P<0.001$) by the age of the kids; at 45 days of age the total protein concentration of AR kids was higher ($P<0.01$) than that of TR kids, with no differences for the remainder of the trial.

4. Discussion

Goat milk production was within the expected range according to previous results obtained in Criollo goats under similar rearing conditions (Paez et al., 2001). The different lengths of the suckling period resulted in savings of 32.7% of goat milk in the AR group. Many studies have found an inverse relationship between intake of milk and solid feed ingestion in calves (Terré et al., 2007; Kosiorowska et al., 2011). In the present study, solid feed intake increased in both groups after weaning, from 11.5 ± 0.4 to 105.3 ± 1.3 g DM per day for AR kids and from 46.4 ± 1.0 to 169.4 ± 5.3 g DM per day for TR kids (Table 2). However, this increase did not compensate for the intake of total solids provided by goat milk, so total DMI for both groups decreased after weaning. This drop in total DMI after weaning was similar for both groups. Post-weaning total DMI (expressed as percentage of body weight) by AR and TR kids was equal to 1.85 % and 1.87 %, respectively. These percentages were lower than those found in 84-day old lambs (2.75 %, calculated from Baldwin et al. (2000)) and in 63-day old calves (2.50 %, calculated from Khan et al. (2007)). This agrees with Sanz Sampelayo et al. (1995), who argue that kid goats

Table 4
Concentrations of glucose, non-esterified fatty acids (NEFA), < beta > -hydroxybutyrate (< beta > HB), blood urea nitrogen (BUN) and total protein of Criollo kids under traditional and alternative rearing systems.

Age (d)	15		30		45		60		90		Effect[c]			
Rearing system	TR	AR	TR	AR	TR	AR	TR	AR	TR	AR	s.e.m	*R*	*T*	*R* × *T*
Glucose (mmol/L)	5.02	5.56	5.19	4.99	3.92	4.07	3.90	3.44	3.37	3.37	0.20	NS	***	NS
NEFA (mmol/L)	0.44	0.44	0.47	0.46	0.50	0.52	0.48	0.42	0.31	0.27	0.03	NS	***	NS
< beta > HB (mmol/L)	0.17	0.15	0.16[a]	0.36[b]	0.14[a]	0.27[b]	0.20	0.19	0.21	0.22	0.02	NS	***	NS
BUN (mmol/L)	9.55	12.71	8.43[a]	14.43[b]	12.27[a]	19.26[b]	17.22	17.18	18.08	16.67	0.66	***	***	***
Total protein (g/dL)	6.07	5.88	5.86	5.46	5.90[a]	6.74[b]	5.53	5.95	6.27	6.59	0.17	NS	***	**

[a] [b]Means with different superscripts in the same row and within same age group indicate statistical differences between treatments ($P < 0.05$).
TR and AR; traditional and alternative rearing systems, respectively. s.e.m; standard error of the mean.
NS not significant.
[c] Effects were treatment (*R*, rearing system), time (*T*) and rearing system × time interaction (*R* × *T*).
** $P \leq 0.01$.
*** $P \leq 0.001$.

have a low voluntary feed intake compared to other ruminants.

Although AR kids doubled the solid feed intake of TR kids at 30–45 days of age, they did not meet their daily energy requirements according to NRC (2007). For this reason AR goat kids lost 63.9 ± 5.19 g of body weight per day, between 30 and 45 days of age. This explains why post-weaning feed efficiency of AR goat kids was negative and why the body weight of AR goat kids was lower than that of TR goat kids at 30–45 days of age. According to Singh-Knights and Knights (2005), the weaning shock is reduced if goat kids are weaned at 9 kg of body weight, 8 weeks of age or at the moment when the solid feed intake reaches 30 g DM per day. None of these criteria were met at weaning of AR group which explains the post-weaning growth depression of these goat kids.

The sale weight of AR kids at 45–60 days of age was lower than the traditional market weight of 8–14 kg achieved with a traditional rearing system in Argentina (Guevara et al., 2009), indicating that early weaned kids could not be sold at the traditional age of marketing in Argentina (between 45 and 60 days of age). However, AR kids achieved a compensatory growth that enabled them to reach a body weight similar to that of TR kids at 75–90 days of age. This compensatory growth was attained due to the higher total DMI (between 45 and 75 days of age) and better feed efficiency (between 75 and 90 days of age), which led to the higher ADG observed between 45 and 90 days of age in AR kids compared to TR kids.

Rumen development is characterized by an increase in organ weight and by the growth of the papillae (Baldwin et al., 2004). The greater weight of the rumen (as % of BW) in AR kids compared with TR kids is consistent with previous findings in the sense that feed in the rumen provides a physical stimulus to increase rumen weight (Baldwin et al., 2004; Suarez et al., 2006; Khan et al., 2011). Contrary to our expectations, differences in rumen weight were observed as early as 21 days of age, when AR kids had ingested a negligible amount of solid feed only during the previous week. This indicates that after the beginning of solid feed intake the rumen of kids undergoes a rapid physical development. The heaviest rumen weights, as percentage of BW, were recorded at 70 and 90 days of age in AR and TR kids, respectively. These values are higher than 2.80%, 2.65%, 2.45% and 2.23% reported for goats of 120, 145, 190 and 220 days of age, respectively (Jelínek, 1995; Mgasa et al., 1994). Rumen weight, relative to body weight, reached its maximum around 40–45 days after weaning. This coincides with Jelínek (1995), who states that growth rate of rumen exceeds that of body weight gain. This may be because there is a priority for developing the organ responsible for absorbing the nutrients necessary for the subsequent growth of the animal after weaning. The highest rumen weight (as percentage of weight of all compartments) was also observed at 70 days of age. Taking into account that the weight of the rumen of an adult ruminant represents about 80% of the weight of all compartments (Lane and Jesse, 1997), at least the physical development of the rumen of goat kids from both rearing systems was reached at around 70 days of age.

The papillae were longer as kid aged. Other researchers argue that the length of the papillae increases both with animal age and with solid feed intake (Baldwin et al., 2004, Amaral et al., 2005). The presence of only physical bulk does not promote development of the papillae. For the normal development of the ruminal epithelium, there should be a viable ruminal fermentation producing short-chain fatty acids in the rumen lumen to trigger the growth of the papillae (Baldwin et al., 2004; Lesmeister et al., 2004; Khan et al., 2011). Propionate and butyrate have a greater stimulatory effect on the development of the rumen papillae than does acetate (Suarez et al., 2006). The fact that no significant differences were found in papillae length between groups of goat kids could be because the carbohydrate composition of the diet did not produce enough ruminal concentrations of propionate and butyrate (Suarez et al., 2006); thus the stimulus on the papillae growth was not enough to achieve great differences between goat kid groups. Moreover, this could be due to the low DMI of goat kids in both groups early in life. However, in both rearing systems the length of the papillae at 90 days of age was similar to that reported for adult goats (Jelínek, 1995; Wang et al., 2009), indicating that both groups of goat kids reached a normal development of the rumen epithelium.

The decrease in blood glucose concentration as goat kid aged indicates a shift in the primary energy source from glucose to short-chain fatty acids. Blood NEFA concentration is closely related to the energy balance of goats, thus when they are in negative energy balance lipolysis increases, with a consequent increase in the serum NEFA concentration (Dønnem et al., 2011). The highest serum NEFA values were observed in AR kids at 45 days of age (15 days after weaning). This is due to the above-mentioned pronounced drop in total DMI after weaning and to a high nutritional transition stress in AR goat kids.

On the other hand, it is well known that there is a direct relationship between nutritional status and serum concentration of protein and albumin, whereby the levels of these metabolites decrease when there is a protein or energy malnutrition (Johnson et al., 1995). However, the effect of malnutrition on the serum protein concentrations is closely related to the duration of nutritional scarcity. Therefore, the shortage has to last a long time before albumins and globulins begin to be used as a protein source (Caldeira et al., 2007). In the present study, the nutritional restriction after weaning was not so long as to reduce the serum protein concentration of AR kids. Instead, these kids had higher values than TR kids at 45 days of age. Many studies have demonstrated that under stressful stimuli such as weaning, animals may respond by increasing blood levels of certain acute phase proteins such as fibrinogen, haptoglobin, ceruloplasmin, α-acid glycoprotein and serum amyloid-A (Arthington et al., 2003, 2005; Hickey et al., 2003; Lynch et al., 2010). For instance, Blanco et al. (2009) found that after weaning, the increase in fibrinogen concentration was higher in early-weaned calves that in traditionally-weaned calves. Furthermore, González et al. (2011)) reported that fasting causes a significant increase in serum haptoglobin concentration in goats. Therefore, the highest concentration of serum proteins of AR kids is attributed to a higher post-weaning stress and a higher production of acute phase proteins by these kids compared to TR kids.

The blood urea nitrogen increases when there is a greater ruminal degradation of protein with an increased production of ammonia (Kanyinji et al., 2009). Although, in periods of energy restriction, the shortfall in energy can meet through the catabolism of body protein which also results in increased concentration of urea (Brickell et al., 2009). The highest concentration of serum BUN at 30 days of age in AR goat kids is attributed to early development of rumen microbial activity and better protein degradation, because these animals had no dietary restrictions at this time and consumed the same quantity of DM than TR goat kids. However, at 45 days of age the highest concentration of serum BUN could be due to both increased ruminal activity and body protein catabolism, because in this period the AR goat kids were losing body weight.

As stated by Baldwin et al. (2004), one of the most defining characteristics of a fully developed and functional rumen, in a fed, non-pregnant and non-lactating animal, is the ruminal production of ketone bodies. However, in adult ruminants the ketone bodies can be produced both in the liver as in the ruminal epithelium (Baldwin et al., 2004). During a negative energy balance the liver produces ketone bodies being able to lead to ketosis (Schlumbohm and Harmeyer, 2004). Ketosis is characterized by biochemical changes such as lower serum glucose levels and higher levels of NEFA and <beta>HB (Quigley et al., 1991). Throughout the test, the average blood glucose concentration was greater than the lower limit of the normal range for goats (2.8–4.2 mmol/L; Kaneko et al., 2008) in both groups of kids. Serum concentration of <beta>HB was always lower than 0.86 mmol/L, limit from which it is considered that goats are experiencing moderate ketosis (Bani et al., 2008; González et al., 2011). This proves that highest <beta>HB concentration in AR kid goats was due to rumen ketogenesis. Furthermore, the fact that NEFA values were similar to those reported in adult goats without ketosis (0.28–0.51 mmol/L, González et al., 2011) supports this assertion. In summary, these blood metabolite profiles indicate a greater reliance on the end products of ruminal fermentation and an earlier metabolic transition in AR goat kids compared to TR goat kids.

5. Conclusions

The alternative rearing system improved the physical and metabolic development of the rumen and promoted the transition of kids from pre-ruminant to ruminant. It was possible to wean Criollo goat kids as early as 30 days of age and to save 32.7% of goat milk. However, early weaning negatively affected the growth performance of goat kids. Therefore, it was not possible to attain the required market weight with the alternative rearing system. Although, early weaned goat kids achieved a compensatory growth that allowed them to reach a marketable weight at an older age. Therefore, in dry years the alternative rearing system could be used but these goat kids should be reared above the habitual age.

Conflict of interest statement

None

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