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Mineral metabolism of pregnant goats under feed restriction

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Abstract. We examined the effects of feed restriction on calcium, phosphorus, magnesium, sodium and potassium metabolism in Oberhasli and Saanen goats during gestation. The 63 goats were distributed into groups that were divided into three levels of feed restriction (0%, 20% and 40% restriction) and slaughtered at different pregnancy stages (80, 110 and 140 days of gestation), in a randomised block design with a 2 × 3 × 3 factorial arrangement. The mineral balance was determined at ~80, 110 and 140 days of gestation. The serum levels of minerals and alkaline phosphatase activity were determined during pregnancy. Mineral retention in the maternal body, femur, empty uterus, mammary gland, fetus and fetal fluid was also determined during gestation. Bone mineral density was measured in the femur. Mixed models with days of gestation, levels of feed restriction, breed and their interactions as fixed effects and blocks as random effect were used for data analysis. In response to the reduction in feed intake, the maternal body uses its mineral reserves to maintain gestation. Physiological adjustments of the goats subjected to 20% feed restriction avoided a decrease in fetal mineral deposition. More severe feed restriction, however, compromised concentrations of phosphorus, sodium and potassium in the fetus, which were the main minerals used by the maternal body, whereas calcium and magnesium deposition in fetuses remained unaffected. At 40% feed restriction, the retention of all minerals in the body decreased, and the fetal dry mass was on average also less than those fetuses from goats without feed restriction. The fetal deposition of phosphorus, sodium and potassium was also lower during 40% restriction.

Additional keywords: gestation, fetal mineral deposition, maternal body, mineral retention, undernutrition.

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Introduction

Goat husbandry for milk and meat production contributes considerably to reducing world hunger, especially in India and countries in Africa and Asia, which have the largest herds (FAO 2005). Goat herds are known to survive in harsh environments such as deserts, semiarid areas and mountain regions (Devendra 1999), where animals often undergo food restriction. Feed deprivation (food shortages in harsh regions, seasonal variation in food availability or even nutritional management strategy), is one of the major nutritional challenges for animals.

The effects of feed restriction can be more serious if it is associated with specific physiological conditions such as pregnancy. Prolonged and severe feed restriction may compromise fetal development, especially at the end of pregnancy when the growth rate of the fetus is greater (Breier 2006). Moreover, the emergence of obesity, type II diabetes, hypertension, cardiovascular diseases, metabolic and behavioural disorders, underdevelopment of the gastrointestinal tract and low feed consumption have been reported in individuals born to mothers subjected to severe nutrient restriction during gestation (Trahair *et al*. 1997; Laporte-Broux *et al*. 2012).

In general, malnourishment during pregnancy primarily affects the mother because nutrients are mostly delivered to the fetus, and mobilisation of maternal deposits causes maternal weight loss and decreases energy uptake by the uterus (Bell and Ehrhardt 2000; Greenwood and Bell 2003). Studies on the fetal growth of sheep and cattle that investigate the consequences of feed restriction at the beginning and in the last third of pregnancy (Breier 2006; Long *et al*. 2009; Demirtas and Özcan 2012) have focussed mainly on maternal energy and protein metabolism (Bell and Ehrhardt 2000). Fetal growth and mineral metabolism in pregnant goats under feed restriction are quite different from that of cattle and sheep, and despite the importance of this information, it has been scarcely investigated (Van Soest 1994; Wilkens *et al*. 2014). Moreover, although the mineral requirements of goats are affected by genotype (Teixeira *et al*. 2013), studies comparing dairy goat breeds are nonexistent. Therefore, the objective of the present study was to evaluate the effects of feed restriction on maternal calcium (Ca), phosphorus (P), magnesium (Mg),

sodium (Na) and potassium (K) metabolism and on the deposition of these minerals in fetuses of Oberhasli and Saanen goats during pregnancy.

Materials and methods

Animals, diet and experimental design

The experimental procedures were previously approved by the Ethics Committee of São Paulo State University in Jaboticabal (#026167–07). The 63 tested Oberhasli (n = 31) and Saanen (n = 32) goats were multiparous (from 2 to 3 years of age on average), non-lactating and non-pregnant. The initial bodyweight (BW) was on average 45.1 ± 1.1 kg and 52.2 ± 1.6 kg for Oberhasli and Saanen goats, respectively. The body condition scores were 2.38 ± 0.09 and 2.87 ± 0.1.4 for Oberhasli and Saanen goats, respectively, which were within the normal range of 5 levels (1 to 5) with halves, was mainly based on palpation of sternum subcutaneous adipose tissue.

At the beginning of the experiment, four Oberhasli and five Saanen goats were slaughtered to estimate the initial body composition of non-pregnant goats, which served as a baseline to compare to values obtained from pregnant goats.

Concerning reproductive management, the goats were naturally mated after oestrus detection during the oestrus period. Oestrus was also induced by hormonal treatment in the anestrous periods as recommended by Freitas *et al*. (1996) and Ritar *et al*. (1984), in which vaginal sponges impregnated with medroxyprogesterone (medroxyprogesterone acetate, 60 mg) were introduced into the goats; after 5 days, the sponges were removed and 0.5 mL of Prolise, (ARSA S.R.L., Buenos Aires, Argentina) a synthetic analogue of PGF2 α, and 2.0 mL of equine chorionic gonadotropin were administered. Oestrus was observed, on average, after 48 h, and then the females were mated. The study was arranged in a completely randomised block design, using a 2 × 3 × 3 factorial scheme that combined two breeds, three slaughter ages and three feeding regimes. Feed restriction started at Day 35 of pregnancy, when the number of fetuses was identified by sonography, and lasted until the pre-established day of the slaughter. As such, 54 twin pregnant goats (27 Saanen and 27 Oberhasli) with similar BW were randomly divided into three groups (nine goats of each breed per group) according to slaughter age (80, 110 and 140 days of gestation). Each group was divided into three blocks with three animals, and each goat in a block was subjected to a different feeding regime [no restriction (0%), 20% and 40% feed restriction]. Animals without feed restriction were fed *ad libitum*, with the feed amount adjusted to allow 15% orts. The amount of feed offered daily to the animals subjected to 20% and 40% feed restriction was based on the amount of food consumed by the goats fed *ad libitum* the previous day.

The goats were held in individual 1.0-m^2 pens equipped with a feeder and water trough. The diet was balanced according to the NRC (2007) requirements for pregnant goats. The diet was provided twice a day, at 0730 hours and 1700 hours. The diet composition is shown in Table 1. After mating, the animals were weighed every 15 days.

Sampling

The goats were slaughtered at 80, 110 or 140 days of gestation, according to the treatment. The BW was measured immediately before slaughter, without previous water or feed deprivation. Goats were stunned using captive bolt pistol before being killed, and their blood was collected and stored for subsequent analysis. The pregnant uterus and mammary gland were the first organs removed. The components of the gravid uterus were separated into empty uterus (uterine tissue with placenta and placentomes), and fetuses and fetal fluid, which contained a combination of amniotic and allantoic fluids. The uterus components and mammary glands were weighed and frozen. The gastrointestinal tract (GIT) was then removed and weighed (kg), with the GIT content weight (kg) representing the difference between the full and empty GIT. The empty bodyweight (EBW) was calculated by subtracting the weight of the GIT content, urinary bladder and gallbladder from the BW immediately before slaughter.

The right femur was removed from the dead goats to measure the mineral density and mineral composition of the bones. The bone mineral density was determined from the radiographs of femur samples, taken by a SiemensTridoro 812E X-ray machine (Siemens, São Paulo, Brazil). The maternal body (MB; carcass, blood, organs, viscera, fat, head, limbs and skin) was ground and

Table 1. Feed and diet composition

Ingredient	%	DM g/kg	Gross energy[A]	Crude protein	Ether extract	Neutral detergent fibre	Calcium	Phosphorus	Magnesium	Sodium	Potassium
							g/kg DM				
Corn ground	32.8	820	3.92	102	29.0	169	0.48	2.97	1.08	0.44	2.8
Soybean meal	12.2	831	4.17	518	18.6	222	2.83	7.27	3.24	0.63	24.8
Corn hay	44.1	852	3.86	102	17.1	580	2.28	2.01	1.79	0.47	11.4
Tifton 65-hay	10.0	872	3.84	78	9.4	784	3.83	2.21	1.93	0.69	18.5
Mineral premix[B]	0.38	990	–	–	–	–	184	73	58	49.4	1.0
NaCl	0.07	980	–	–	–	–	–	–	–	397	–
Limestone	0.33	950	–	–	–	–	501	–	0.3	0.22	0.06
Whole diet	100	842	3.27	125	17.0	355	3.87	2.76	1.69	1.42	9.19

[A]Gross energy in Mcal/kg of DM.

[B]Premix contained 73 g of P/kg, 190 g of Ca/kg, 62 g of Na/kg, 90 g of Cl/kg, 44 g of Mg/kg, 30 g of S/kg, 1.35 mg of Zn/kg, 340 mg of Cu/kg, 940 mg of Mn/kg, 1.06 mg of Fe/kg, 3 mg of Co/kg, 16 mg of I/kg, 10 mg of Se/kg, maximum of 730 mg of F/kg.

homogenised. A 1-kg sample of the MB was separated and frozen for further analysis of minerals. The empty uterus, fetuses, mammary glands and femur of the goats were also ground and homogenised and samples of these tissues were kept separated for future mineral analyses. The samples were freeze-dried for 72 h. The body, mammary gland and femur samples were then defatted and analysed to determine mineral content.

The set of goats slaughtered at 140 days of gestation were used for periodical blood sampling (at 1, 35, 50, 65, 80, 95, 110, 125 and 140 days of gestation), before morning feeding. The blood samples were collected from the jugular vein in 10-mL vacuum tubes without anticoagulant and allowed to clot. Thereafter, the serum was separated by centrifugation (1370*g*; 20 min; 4°C) and stored at −20°C until analysis.

Digestibility trial

The set of goats slaughtered at 140 days of gestation were previously subjected to three digestibility assays during pregnancy. To that end, they were placed in metabolism cages with controlled feed and ort, and total faeces and urine were collected for 5 days after 2 days of adjustment to the environment. The assays were performed at 80, 110 and 140 days of pregnancy. A total of 20% of the excreted faeces was collected, producing a 5-day composite. Urine was collected in buckets containing 50 mL of 7.2 N H_2SO_4, and a 10% aliquot was removed daily and frozen for further analysis. The apparent absorption was defined as the mineral fraction that was ingested but not excreted in the faeces. The mineral balance was calculated by subtracting the content eliminated in the faeces and urine from the amount ingested. Leftover faeces, feed and feed samples were dried in a forced air oven at 55°C for 72 h.

Chemical analyses

The bone mineral density was estimated in the proximal and distal femoral epiphysis and in the femoral diaphysis using X-ray images and a 12-point scale for estimating the aluminium concentration (aluminium alloy 6063, ABNT 2005), as described by Araújo *et al*. (2011).

The DM and fat content in the samples of feed ingredients, leftovers, faeces, empty body, mammary gland, fetus, femur, empty uterus and fetal fluid were determined according to Association of Official Analytical Chemists (AOAC) methods 930.15 and 920.39, respectively (AOAC 1990). Because of the high fat content in the mammary gland, empty body and femur, ether extract analysis was adapted by defatting these samples with reflow in petroleum ether for 8 h. The feed samples were analysed for total ash by combustion at 600°C for 3 h, according to method 942.05 (AOAC 1990) and for crude protein by nitrogen (N) determination with a Leco-FP 528 LC using the Dumas method, as described by Etheridge *et al*. (1998). The neutral detergent fibre (NDF) in the diet ingredients was determined by the method described by Robertson and Van Soest (1981). The gross energy density was obtained using a calorimetry bomb.

The mineral content in the empty body, femur, fetus, empty uterus, fetal fluid, mammary gland, feed ingredients, feed leftovers, faeces and urine was determined by digestion in nitric (NHO_3) + perchloric ($HClO_4$) (AOAC 1990; method 935). The calcium (Ca) and magnesium (Mg) concentration were measured by atomic absorption (AOAC 1990; method 935), sodium (Na) and potassium (K) by atomic emission (Fritz and Schenk 1979) and phosphorus (P) by colourimetric assays (AOAC 1990; method 935).

The serum Ca, P and Mg levels (mmol/L) and alkaline phosphatase (ALP) activity (U/L) were determined by colourimetric procedures, using commercial kits (LABTEST, Lagoa Santa MG, Brazil) with spectrophotometry (model Bio 2000 LABQUEST to TABTEST). A ROCHE 9180 electrolyte analyser (Roche Diagnostics, Mannheim, Germany) was used to determine the serum K, Na and ionised Ca.

Equations to predict body composition at conception

Six structures were considered for the calculation of mineral retention: MB, fetuses, fetal fluid, empty uterus, mammary gland and femur. The MB at slaughter was calculated by subtracting the sum of the weights of the gravid uterus and mammary glands from the EBW (Eqn 1).

$$\text{MB} = \text{EBW} - (\text{gravid uterus weight} + \text{mammary gland weight}) \quad (1)$$

The fresh mass retention was obtained from the difference between the maternal BW, mammary gland weight, empty uterus weight and femur weight at slaughter time and their weights at the beginning of pregnancy, estimated from baseline animals [Eqns (2) to (8)]. Changes in bone mineral density were estimated using a similar procedure [Eqns (9) to (13)].

$$\text{EBWi} = -11.438 \pm 4.41 + 1.09 \pm 0.07 \times \text{BW at mating} \quad (2)$$

where, EBWi = initial empty BW (kg); BW = bodyweight (kg) at mating, with R^2 = 0.96, root mean square error (RMSE) = 2.25 and $P < 0.0001$

$$\text{MBi} = 0.32 \pm 0.56 + 0.982 \pm 0.01 \times \text{EBWi} \quad (3)$$

where, MBi = initial maternal bodyweight (kg), with R^2 = 0.99, RMSE = 0.26 and $P < 0.0001$

$$\text{Initial gland} = -110.4 \pm 95.5 + 9.80 \pm 1.85 \times \text{MBi (Oberhasli)} \quad (4)$$

$$\text{Initial gland} = -110.4 \pm 95.5 + 10.2 \pm 2.29 \times \text{MBi (Saanen)} \quad (5)$$

where, initial gland = initial mammary gland weight (g), with R^2 = 0.76, RMSE = 80.27 and P = 0.0017

$$\text{Initial uterus} = (\text{EBWi} - \text{MBi}) - \text{initial gland} \quad (6)$$

where, initial uterus = initial empty uterus weight (g).

$$\text{Initial femur} = 0.72 \pm 0.06 - 0.0079 \pm 0.001 \times \text{MBi (Oberhasli)} \quad (7)$$

$$\text{Initial femur} = 0.72 \pm 0.06 - 0.0084 \pm 0.001 \times \text{MBi (Saanen)} \quad (8)$$

where, initial femur = initial femur weight (g), with $R^2 = 0.83$, RMSE = 0.04 and $P = 0.0003$

$$\text{Initial BMD of diaphysis} = 1.40 \pm 1.21 + 0.018 \pm 0.0003 \times \text{MBi (Oberhasli)} \quad (9)$$

$$\text{Initial BMD of diaphysis} = 1.40 \pm 1.21 + 0.015 \pm 0.0004 \times \text{MBi(Saanen)} \quad (10)$$

where, initial BMD of diaphysis = initial bone mineral density of diaphysis in the femur (mm aluminium), with $R^2 = 0.79$, RMSE = 0.75 and $P = 0.0019$

$$\text{Initial BMD of proximal epyphysis} = 12.8 \pm 2.09 - 0.045 \pm 0.01 \times \text{FWi (Oberhasli)} \quad (11)$$

$$\text{Initial BMD of proximal epyphysis} = 12.8 \pm 2.09 - 0.050 \pm 0.01 \times \text{FWi (Saanen)} \quad (12)$$

where, initial BMD of proximal epiphysis = initial bone mineral density of proximal epiphysis in the femur (mm aluminium); FWi = initial femur weight (Eqns 7 and 8), with $R^2 = 0.61$, RMSE = 0.65 and $P = 0.015$

$$\text{Initial BMD of distal epyphysis} = 7.24 \pm 2.07 + 0.002 \pm 0.0006 \times \text{MBi} \quad (13)$$

where, initial BMD of distal epiphysis = initial bone mineral density of distal epiphysis in the femur (mm aluminium); MBi = initial maternal bodyweight (kg), with $R^2 = 0.40$, RMSE = 1.38 and $P = 0.05$.

The dry mass and minerals retention were obtained from the difference between the composition of the MB, empty uterus, fetuses, fetal fluids, mammary gland, and femur at slaughter time and their composition at the beginning of pregnancy. The dry mass at the beginning of pregnancy of the MB was significantly correlated with the initial MB weight (Eqn 14). The dry mass of the empty uterus, mammary gland, and femur were considered 17.8%, 42.6%, and 83.2% of their fresh weights, respectively.

$$\text{Dmi} = 22.9 \pm 8.13 + 0.549 \pm 0.164 \text{ MBi} \quad (14)$$

where, Dmi = dry mass of the MB at the beginning of pregnancy (%), with $R^2 = 0.62$, RMSE = 3.55 and $P = 0.0124$.

Because we did not find a significant regression correlated with the dry mass, the mineral compositions of the MB, empty uterus, mammary gland and femur at the beginning of pregnancy were estimated using the average compositions found in the baseline goats (Table 2). The compositions of the fetuses and fetal fluid at the beginning of pregnancy were assigned a value of zero.

Statistics

To estimate the fresh weight at the beginning of pregnancy, we obtained regression equations for MB, empty uterus, mammary gland, femur, and femur bone mineral density based on the baseline composition of non-pregnant goats. The calculations were performed using the SAS MIXED procedure of SAS (version 9.2, SAS Institute Inc., Cary, NC, USA). The analysis assessed the effects of breed on the regression models obtained. The dry mass and mineral composition of the MB, empty uterus, mammary gland, and femur at the beginning of pregnancy were estimated by regression against the fresh weight and dry mass, respectively. When the regression was not significant we used the average mineral compositions of the baseline goats.

The feed intake and mineral balance data were evaluated in a completely randomised block design with repeated-measures over time. Mixed models were applied with fixed effects for breed (1 d.f.), level of feed restriction (1 d.f.), days of gestation (2 d.f. for 80, 110 and 140 days), the interaction of these factors and the random effects of block (2 d.f.) and the residual error, using the MIXED procedure of SAS (version 9.2). The covariance matrix that best fit the data according to the Bayesian information criterion was selected.

The statistical model was:

$$Y_{ijkl} = \mu + B_i + a_{j:il} + R_k + D_l + (B_i \times R_k) + (B_i \times D_l) + (R_k \times D_l) + (B_i \times R_k \times D_l) + \varepsilon_{ijkl}$$

where, μ = overall intercept mean; B = effect of the breed i; a = effect of the block j; R = effect of the restriction level k; D = effect of days of gestation l; interactions; and ε = error associated with each Y_{ijkl}.

The mineral retention data were analysed by mixed models for breed (1 d.f.), days of gestation (2 d.f.), feed restriction level (2 d.f.) and the interaction of these factors (4 d.f.) as fixed effects and block (2 d.f.) and error as random effects, using the MIXED procedure of SAS (version 9.2). Residual variances, distinct to 'level of restriction' and 'days of gestation' subclasses, were modelled using the GROUP option of the REPEATED command.

The serum minerals and ALP activity were analysed in a completely randomised block design with repeated-measures over time. Mixed models were applied with breed (1 d.f.),

Table 2. Mineral composition (% of dry mass) of the maternal body, empty uterus, mammary gland and femur at the beginning of pregnancy, estimated from baseline animals

Mean ± standard error of mean

Item	Maternal body	Empty uterus	Mammary gland	Femur
Calcium	2.95 ± 0.212	0.114 ± 0.0092	0.317 ± 0.0856	16.0 ± 0.460
Phosphorus	1.54 ± 0.108	0.726 ± 0.0854	0.420 ± 0.0558	7.09 ± 0.431
Magnesium	0.0805 ± 0.0054	0.062 ± 0.0046	0.033 ± 0.0035	0.305 ± 0.020
Sodium	0.250 ± 0.0187	1.29 ± 0.0982	0.463 ± 0.0671	0.490 ± 0.036
Potassium	0.286 ± 0.0253	0.970 ± 0.121	0.276 ± 0.0466	0.034 ± 0.0049

level of feed restriction (2 d.f.), days of gestation (8 d.f.), the interaction of these factors as fixed effects and the random effects of blocks (2 d.f.) and error, using the MIXED procedure of SAS (version 9.2). The covariance matrix that best fits the data according to the Bayesian information criterion was selected.

High-level interactions without statistical significance obtained in data analyses were sequentially removed. Significant means for days of gestation and levels of restriction were compared using Tukey's minimum significant difference (i.e. option PDIFF adjust = Tukey of the LSMEANS command). Residual graphs were used to detect the violation of assumptions in ANOVA, such as variance heterogeneity, auto correlated error, and the presence of outliers. The significance level was set at $P \leq 0.05$. Trends were considered at $0.05 \leq P \leq 0.10$.

Results

Intake, mineral availability and balance

The mineral and DM intake decreased ($P < 0.05$) with feed restriction and decreased at the end of pregnancy ($P < 0.01$), from Day 110 of pregnancy to Day 140 (Table 3). The Ca ($P = 0.07$), P and K ($P < 0.01$) balances and Na losses ($P < 0.01$) in the goats decreased with an increase in the feed restriction level (Table 3). A decrease in the P ($P = 0.09$) and an increase in the Mg ($P < 0.01$) balances were also observed during pregnancy in all treatments.

The apparent availability (AA) of Ca decreased with increased feed restriction ($P = 0.07$), whereas the AA of P and K did not change. Additionally, the excretion in urine as a proportion of metabolic EBW of all of the minerals studied was similar among feed restrictions.

Mineral retention

The MB lost dry mass at 20% feed restriction and at 40% feed restriction ($P < 0.01$; Table 4). Similarly, the retention of almost all off the minerals decreased significantly in the body of goats subjected to 40% feed restriction, except for K retention ($P = 0.06$). During fetal development, Ca, P and Mg retention in the MB decreased ($P < 0.05$). Additionally, Saanen goats exhibited negative Ca and P retention ($P < 0.01$). The interaction observed in Na retention in the MB means that Saanen goats subjected to 40% feed restriction had higher body Na losses ($P < 0.05$) than Oberhasli goats.

The dry mass of twin fetuses from goats subjected to 40% feed restriction was lower than that of fetuses from goats without feed restriction ($P < 0.05$; Table 5). Similarly, at 40% of feed restriction, fetal Na ($P = 0.06$) and K ($P < 0.05$) retention decreased. The retention of all minerals in the fetuses and the fetuses' weights increased significantly with the increase of gestation days ($P < 0.05$).

The 40% feed restriction resulted in higher dry mass ($P < 0.05$) and Na retention ($P = 0.06$) in the fetal fluid (Table 5). The fetal fluid of Oberhasli goats had a higher retention of fresh fluid and water ($P < 0.01$) and a lower retention of P ($P < 0.05$). With pregnancy development, the amount of fetal fluid retained and its concentrations of P, Mg and K increased ($P < 0.01$). However, the interaction shows that at 110 days of pregnancy the K retention was higher in those goats fed with 40% feed restriction ($P < 0.05$).

Feed restriction did not affect mineral retention in the empty uterus (Table 5). Fresh mass, dry mass, Mg, and K retention in the empty uterus increased during pregnancy development ($P < 0.05$).

The mammary gland dry weight ($P < 0.05$) and K ($P < 0.01$) retentions decreased ($P < 0.01$) with the feed restriction (Table 6). The interaction between feed restriction and gestation days affected P retention, which decreased at 80 days of gestation in feed restriction treatments ($P < 0.01$) in the mammary gland. This effect was limited to that period, and at 110 and 140 days of gestation, P retention in the mammary gland did not differ among treatments. Additionally, the

Table 3. Mineral intake and balance in Oberhasli and Saanen goats at 80, 110 and 140 days of gestation

a,b, Different letters on the same line indicate differences among feed restriction according to Tukey's test ($P < 0.05$). A,B,C, Different letters on the same line indicate differences among gestation days according to Tukey's test ($P < 0.05$). n.s., not significant ($P > 0.10$); *, $P < 0.05$; **, $P < 0.01$. $EBW^{0.75}$, metabolic empty bodyweight; s.e.m., standard error of least-squares means

Item	Treatments											*P*-value		
	Breed			Feed restriction				Days						
	Oberhasli	Saanen	s.e.m.	0	20	40	s.e.m.	80	110	140	s.e.m.	Breed	Feed restriction	Days
							Consumption (*g*/*day.EBW*$^{0.75}$)							
DM	44.0	48.9	3.02	53.9a	46.3ab	39.1b	3.74	46.6A	43.9A	33.0B	3.94	n.s.	*	**
Calcium[A]	0.23	0.25	0.02	0.28a	0.24ab	0.19b	0.03	0.24A	0.23A	0.17B	0.02	n.s.	**	**
Phosphorus	0.14	0.16	0.01	0.18a	0.15ab	0.13b	0.01	0.16A	0.15A	0.11B	0.01	n.s.	**	**
Magnesium	0.08	0.09	0.005	0.10a	0.08ab	0.07b	0.007	0.08A	0.08A	0.06B	0.007	n.s.	*	**
Sodium	0.04	0.04	0.003	0.05a	0.04ab	0.04b	0.003	0.04A	0.04A	0.03B	0.004	n.s.	*	**
Potassium	0.43	0.48	0.03	0.52a	0.45ab	0.38b	0.04	0.45A	0.43A	0.32B	0.04	n.s.	*	**
							Balance (*mg*/*day.EBW*$^{0.75}$)							
Calcium	15.2	30.7	10.3	34.0a	34.8ab	–0.007b	12.4	32.0	11.7	25.1	14.1	n.s.	0.07	n.s.
Phosphorus	71.3	91.7	10.9	107a	77.3ab	59.4b	12.3	107A	71.1AB	66.7B	14.6	n.s.	**	0.09
Magnesium	–44.8	–23.4	9.66	–47.0	–20.7	–34.6	11.6	–58.6B	–31.7AB	–11.9A	13.2	0.09	n.s.	*
Sodium	–61.3	–66.2	21.4	–134b	–25.7a	–31.0a	25.5	–67.4	–79.6	–44.0	29.1	n.s.	**	n.s.
Potassium	173	255	42.2	345a	188ab	108b	46.2	284	218	139	57.3	n.s.	**	n.s.

[A]Interaction between breed and feed restriction ($P < 0.05$).

Table 4. Mineral retention in the maternal body of feed-restricted Oberhasli and Saanen goats at 80, 110 and 140 days of gestation

a,b, Different letters on the same line indicate differences among feed restriction according to Tukey's test ($P < 0.05$). A,B,C, Different letters on the same line indicate differences among gestation days according to Tukey's test ($P < 0.05$). n.s., not significant ($P > 0.10$); *, $P < 0.05$; **, $P < 0.01$. s.e.m., standard error of least-squares means; BW, bodyweight; EBW, empty bodyweight; MBW, maternal bodyweight; AMBW, average maternal bodyweight; Ca, calcium; P, phosphorus; Mg, magnesium; K, potassium; Na, sodium; B, Breed; R, feed restriction levels; D, gestation days

Item	Treatments											*P*-value			
	Breed			Feed restriction				Days							
	Oberhasli	Saanen	s.e.m.	0	20	40	s.e.m.	80	110	140	s.e.m.	Breed	Feed restriction	Days	Interaction
BW (kg)	54.5	65.1	1.70	62.4a	61.0ab	56.0b	1.90	55.6B	63.2A	60.6AB	2.09	**	*	*	n.s.
EBW (kg)	48.0	56.7	1.76	54.6a	53.8ab	48.6b	1.95	47.5B	55.7A	53.9AB	2.09	**	*	*	n.s.
MBW at slaughter (kg)	37.8	48.0	1.62	43.0ab	45.1a	40.6b	2.02	40.9B	47.8A	40.0B	2.06	**	**	*	n.s.
AMBW (kg)	38.1	47.9	1.50	43.2	43.3	42.5	1.63	41.1	45.8	42.0	1.78	**	n.s.	n.s.	n.s.
Fresh mass retention (kg)	1.63	2.03	0.91	5.41a	2.82b	–2.73c	1.14	5.80A	2.61B	–2.91C	1.34	n.s.	**	**	n.s.
Dry mass retention (kg)	0.75	1.19	0.67	3.50a	1.25b	–1.84c	0.84	3.32A	1.23B	–1.65C	0.98	n.s.	**	**	n.s.
Ca retention (g/kg AMBW)	2.26	–1.54	0.86	1.95a	0.44a	–1.31b	0.98	1.99a	0.78ab	–1.69b	1.04	**	*	*	n.s.
P retention (g/ kg AMBW)	1.23	–0.74	0.41	0.99a	0.26ab	–0.51b	0.46	1.11a	0.47a	–0.82b	0.47	**	*	*	n.s.
Mg retention (g/kg AMBW	0.12	0.07	0.02	0.16a	0.10ab	0.03b	0.03	0.13a	0.13a	0.04b	0.03	n.s.	**	*	n.s.
Na retention (g/kg AMBW)	0.69	0.17	0.06	0.57a	0.54a	0.18b	0.08	0.52	0.44	0.33	0.08	**	**	n.s.	B × R*
K retention (g/ kg AMBW)	0.50	0.26	0.12	0.58	0.40	0.15	0.14	0.52	0.48	0.13	0.17	n.s.	0.06	n.s.	n.s.

mammary gland fresh and dry weights and Mg and K retentions increased ($P < 0.01$) with pregnancy development (Table 6).

Saanen goats showed higher Ca, P, Mg ($P < 0.05$) and Na ($P = 0.06$) retention in the femur (Table 7). The P deposition in the femur varied during pregnancy, and the highest retention was found at 110 days of gestation ($P < 0.01$).

The bone mineral densitometry retention of the distal epiphysis, proximal epiphysis and diaphysis was –0.33 ± 0.490, –1.865 ± 0.250 and 0.185 ± 0.292, respectively, and was not affected by any of the treatments.

Blood measurements

The serum Ca levels were higher in Saanen (1.98 ± 0.0424 mmol/L) than in Oberhasli goats (1.81 ± 0.0449 mmol/L; $P < 0.05$). Moreover, irrespective of breed and feed restriction, serum Ca levels decreased at 110 days of pregnancy ($P < 0.01$; Fig. 1). ALP was not affected by breed and feed restriction, and its activity increased at Day 50 of pregnancy and then gradually decreased ($P < 0.01$; Fig. 1). Serum Mg levels were higher in Saanen goats than Oberhasli goats ($P < 0.01$) at 140 days gestation (Fig. 2). Feed restriction did not change serum minerals and ALP activity, except for K levels (Fig. 3), which were higher in Oberhasli goats fed *ad libitum* than in Saanen goats ($P < 0.05$).

Discussion

To the extent of our knowledge, this is the first study addressing the metabolism of Ca, P, Mg, Na and K in pregnant dairy goats under feed restriction that shows the consequences for different pregnancy products. Our results may help guide nutrient management strategies for pregnant goats, highlighting the importance of mineral supplementation during periods of feed scarcity.

In the present study, a decrease of mineral balance was observed with feed restriction, probably because the intake of minerals decreased whereas their excretion remained the same after feed restriction. Despite expectations, we did not observe neither an increase in mineral AA nor differences in mineral excretion in the urine with the feed restriction. Our findings are in accordance with those reported by Kronqvist *et al*. (2011) in periparturient dairy cows. They found that Ca AA did not change with different levels of Ca intake; however, the Ca excretion in urine was greater in cows fed a lower amount of Ca. These findings indicate that ruminant metabolism during pregnancy responds to mineral restriction by mobilising body reserves rather than increasing the AA. This theory can be supported by the decrease of mineral retention in the MB observed in this study. However, all of the mechanisms involved in these metabolic female responses are still not well known, and more studies are needed to identify them.

The mineral and mass retentions observed in the empty uterus indicate the ability of the MB to sustain fetal nutrition despite feed restriction. Furthermore, fetal growth can be directly related to the placental mass, with the uterus serving as the main mediator of nutrient transfer from mother to fetus (Hafez and Hafez 2000; Bell *et al*. 2005). However, the results of mineral femur retention observed in the present study did not indicate mineral mobilisation in the MB. Femur bone mineral density and retention have been successfully used to

Table 5. Mineral retention in pregnant uterus components (fetuses, fetal fluid, and empty uterus) of feed-restricted Oberhasli and Saanen goats at 80, 110 and 140 days of gestation

a,b, Different letters on the same line indicate differences among feed restriction according to Tukey's test ($P < 0.05$). A,B,C, Different letters on the same line indicate differences among gestation days according to Tukey's test ($P < 0.05$). n.s., not significant ($P > 0.10$); *, $P < 0.05$; **, $P < 0.01$. s.e.m., standard error of least-squares means; Ca, calcium; P, phosphorus; Mg, magnesium; K, potassium; Na, sodium; AFW, average femur weight; AFFW, average fetal fluid weight; AEUW, average empty uterus weight; B, Breed; R, feed restriction levels; D, gestation days

Item	Treatments											*P*-value			
	Breed			Feed restriction				Days							
	Oberhasli	Saanen	s.e.m.	0	20	40	s.e.m.	80	110	140	s.e.m.	Breed	Feed restriction	Days	Interaction
Fetuses															
Fetuses weight (kg)	3.10	2.88	0.11	2.99	3.15	2.84	0.15	0.477C	2.45B	6.05A	0.18	n.s.	n.s.	**	n.s.
AFW (g)	1553	1441	54.8	1495	1574	1422	75.6	239C	1227B	3026A	91.6	n.s.	n.s.	**	n.s.
Fresh mass retention (g)	3104	2883	109	2990	3149	2844	151	477C	2453B	6052A	183	n.s.	n.s.	**	n.s.
Dry mass retention (g)	458	452	35.2	462a	459a	445b	25.0	45.1B	354B	968A	54.3	n.s.	*	**	n.s.
Ca retention (mg/g AFW)	13.5	13.3	0.67	13.3	14.7	12.2	1.12	8.24C	14.1B	17.8A	1.31	n.s.	n.s.	**	n.s.
P retention (mg/g AFW)	8.33	8.52	0.46	8.43a	9.76a	7.09b	0.78	5.64B	9.27A	10.4A	0.68	n.s.	*	**	n.s.
Mg retention (mg/g AFW)	0.42	0.45	0.02	0.44	0.46	0.40	0.02	0.33B	0.45A	0.52A	0.03	n.s.	n.s.	**	n.s.
Na retention (mg/g AFW)	3.96	4.32	0.27	4.37	4.46	3.59	0.35	3.48B	4.37AB	4.56A	0.39	n.s.	0.06	*	n.s.
K retention (mg/g AFW)	2.83	2.91	0.13	2.99ab	3.18a	2.44b	0.13	2.28B	3.33A	3.00A	0.25	n.s.	*	**	n.s.
Fetal fluid															
AFFW (g)	1154	898	53.9	1021	999	1059	66.7	736C	988B	1355A	65.0	**	n.s.	**	n.s.
Fresh fluid retention (g)	2212	1876	76.4	2062	2055	2014	112	1408C	1968B	2755A	176	**	n.s.	**	n.s.
Dry mass retention (g)	39.5	27.8	3.32	29.4b	29.9b	41.6a	2.70	24.1B	30.9B	45.9A	5.24	**	**	**	n.s.
Ca retention (mg/g AFFW)	0.20	0.21	0.01	0.21	0.21	0.20	0.01	0.20	0.23	0.18	0.01	n.s.	n.s.	n.s.	n.s.
P retention (mg/g AFFW)	0.07	0.10	0.01	0.09	0.08	0.09	0.01	0.05B	0.08B	0.12A	0.02	*	n.s.	**	n.s.
Mg retention (mg/g AFFW)	0.08	0.08	0.01	0.08	0.08	0.08	0.01	0.05B	0.08AB	0.11A	0.01	n.s.	n.s.	**	n.s.
Na retention (mg/g AFFW)	3.28	2.52	0.34	2.51	2.71	3.47	0.35	3.56	2.68	2.46	0.42	n.s.	0.06	n.s.	n.s.
K retention (mg/g AFFW)	0.92	0.86	0.08	0.86	0.79	1.02	0.12	0.40B	0.98A	1.28A	0.14	n.s.	n.s.	**	R × D*
Empty uterus															
AEUW (g)	1003	1037	62.2	1146	951	962	128	818B	1160A	1082A	77.6	n.s.	n.s.	**	n.s.
Fresh mass retention (g)	1714	1626	85.4	1810	1615	1585	163	1362B	1890A	1757A	120	n.s.	n.s.	**	n.s.
Dry mass retention (g)	219	220	15.9	227	231	200	22.2	173B	231A	254A	23.3	n.s.	n.s.	*	n.s.
Ca retention (mg/g AEUW)	0.38	0.42	0.03	0.39	0.46	0.35	0.05	0.40	0.35	0.45	0.04	n.s.	n.s.	0.08	n.s.
P retention (mg/g AEUW)	2.30	2.23	0.09	2.41	2.21	2.17	0.15	2.09	2.27	2.44	0.14	n.s.	n.s.	n.s.	n.s.
Mg retention (mg/g AEUW)	0.21	0.20	0.01	0.20	0.20	0.20	0.01	0.18B	0.20AB	0.23A	0.01	n.s.	n.s.	*	n.s.
Na retention (mg/g AEUW)	4.06	3.48	0.18	3.93	3.84	3.55	0.26	3.68	3.78	3.86	0.26	*	n.s.	n.s.	n.s.
K retention (mg/g AEUW)	3.49	3.03	0.17	3.55	3.30	2.94	0.24	2.82B	3.02B	3.93A	0.28	0.07	n.s.	*	B × R × D*

Table 6. Mineral retention in the mammary gland of feed-restricted Oberhasli and Saanen goats at 80, 110 and 140 days of gestation

a,b, Different letters on the same line indicate differences among feed restriction according to Tukey's test ($P < 0.05$). A,B,C, Different letters on the same line indicate differences among gestation days according to Tukey's test ($P < 0.05$). n.s., not significant ($P > 0.10$); *, $P < 0.05$; **, $P < 0.01$. s.e.m., standard error of least-squares means; Ca, calcium; P, phosphorus; Mg, magnesium; K, potassium; Na, sodium; AMGW, average mammary gland weight; B, Breed; R, feed restriction levels; D, gestation days

Item[A]	Treatments											*P*-value			
	Breed			Feed restriction				Days							
	Oberhasli	Saanen	s.e.m.	0	20	40	s.e.m.	80	110	140	s.e.m.	Breed	Feed restriction	Days	Interaction
AMGW (g)	929	1016	80.2	1088	901	930	96.5	421C	897B	1599A	174	n.s.	n.s.	**	n.s.
Fresh mass retention (kg)	1272	1258	135	1476	1183	1136	165	295C	1127B	2373A	274	n.s.	n.s.	**	n.s.
Dry mass retention (kg)	361	400	41.9	469a	329b	343b	50.1	77.9C	327B	737A	89.7	n.s.	*	**	n.s.
Ca retention (mg/g AMGW)	1.88	2.08	0.48	1.88	1.24	2.83	0.64	1.77	1.84	2.33	0.73	n.s.	n.s.	n.s.	n.s.
P retention (mg/g AMGW)	2.70	2.38	0.33	3.52a	1.72b	2.38ab	0.45	2.20	2.69	2.73	0.57	n.s.	*	n.s.	R × D**
Mg retention (mg/g AMGW)	0.31	0.27	0.04	0.34	0.26	0.27	0.06	0.12C	0.27B	0.47A	0.05	n.s.	n.s.	**	n.s.
Na retention (mg/g AMGW)	2.93	2.25	0.19	2.67	2.57	2.53	0.25	2.12	2.86	2.78	0.25	*	n.s.	n.s.	n.s.
K retention (mg/g AMGW)	1.42	1.16	0.11	1.61a	1.36a	0.90b	0.15	0 .63B	1.55A	1.70A	0.14	n.s.	**	**	n.s.

Table 7. Mineral retention in the femur of feed-restricted Oberhasli and Saanen goats at 80, 110 and 140 days of gestation

a,b, Different letters on the same line indicate differences among feed restriction according to Tukey's test ($P < 0.05$). A,B, Different letters on the same line indicate differences among gestation days according to Tukey's test ($P < 0.05$). n.s., not significant ($P > 0.10$); *, $P < 0.05$; **, $P < 0.01$. s.e.m., standard error of least-squares means; Ca, calcium; P, phosphorus; Mg, magnesium; K, potassium; Na, sodium; AFW, average femur weight; B, Breed; R, feed restriction levels; D, gestation days

Item	Treatments											*P*-value			
	Breed			Feed restriction				Days							
	Oberhasli	Saanen	s.e.m.	0	20	40	s.e.m.	80	110	140	s.e.m.	Breed	Feed restriction	Days	Interaction
AFW (g)	153	148	2.11	150	153	148	2.57	150	149	152	2.75	n.s.	n.s.	n.s.	n.s.
Ca retention (mg/g AFW)	–3.50	9.51	4.60	0.27	7.85	0.89	5.01	0.58	11.2	–2.76	6.52	*	n.s.	n.s.	n.s.
P retention (mg/g AFW)	–0.32	6.00	1.60	0.76	4.48	3.28	2.77	–0.58B	8.40A	0.70B	2.63	**	n.s.	**	n.s.
Mg retention (mg/g AFW)	–0.03	0.46	0.12	0.23	0.27	0.15	0.12	0.11	0.38	0.16	0.15	**	n.s.	n.s.	n.s.
Na retention (mg/g AFW)	1.40	1.83	0.17	1.62	1.64	1.58	0.20	1.37	1.82	1.65	0.23	0.06	n.s.	n.s.	n.s.
K retention (mg/g AFW)	0.04	0.03	0.05	0.03ab	0.005b	0.07a	0.09	–0.02	0.14	–0.01	0.08	n.s.	*	n.s.	B × R × D**

evaluate the nutritional status of goats (Araújo *et al*. 2011), but these procedures do not indicate the feed restriction effects on bones, possibly because the femur is not the appropriate bone for that assessment. Bone resorption in response to the degree of feed restriction is detected initially in the first cervical vertebrae, pelvic bones, cranium and jaw (Benzie *et al*. 1956). These bones would therefore be better to analyse and evaluate bone resorption in response to feed restriction during critical periods such as pregnancy.

The negative retention of Ca that occurred in the MB after 40% feed restriction could be related to Ca mobilisation in order to ensure Ca deposition in the fetus even when serum Ca decreases during pregnancy. According to Kovacs (2003), maternal hypocalcemia does not compromise fetal development, which is maintained by adjustments in placental mechanisms for Ca uptake from Ca-deficient maternal blood. Similarly, it was observed in sheep that fetal blood Ca levels exceed those of maternal blood from 35 days of gestation onward, and Ca is transferred to the fetus against a concentration gradient (Kovacs 2003). However, fetal mass growth was compromised under the most severe feed restriction despite maternal metabolism efforts. Therefore, our

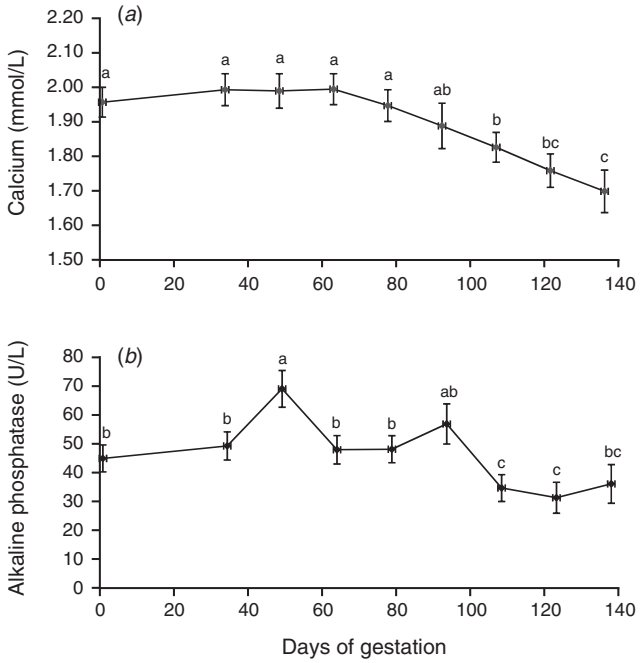

Fig. 1. (*a*) Serum calcium levels and (*b*) alkaline phosphatase activity (±s.e.m.) in dairy goats during pregnancy.

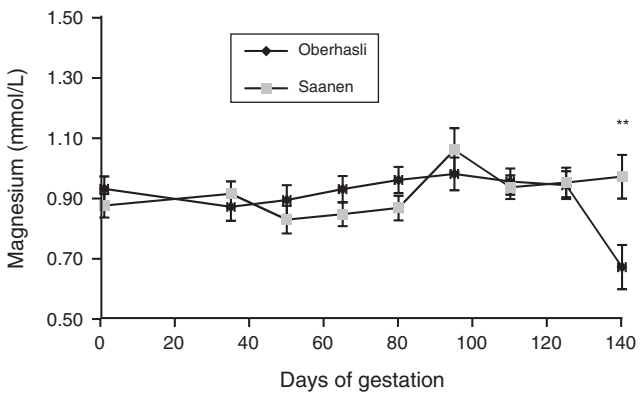

Fig. 2. Serum magnesium levels (±s.e.m.) in Oberhasli and Saanen goats during pregnancy. **, $P < 0.01$.

results are in agreement with other studies reporting that the MB under feed restriction cannot support normal fetal development (Scheaffer *et al*. 2001; Osgerby *et al*. 2002; Long *et al*. 2009).

The feed restriction imposed in the present study was not limited to minerals but also included other nutrients. Pregnancy is characterised by high energy demand, and the MB under feed deficiency mobilises reserves such as adipose and muscle tissue to meet the needs of the pregnant uterus (Bell and Ehrhardt 2000; Scheaffer *et al*. 2001). Under fasting or severe malnourishment conditions, the MB of ruminants undergoes gluconeogenesis using amino acids from muscle and glycerol from adipose tissue (Bell *et al*. 2005; Pethick *et al*. 2005; Kozloski *et al*. 2009). Gluconeogenesis is energetically expensive because it consumes six high-energy phosphate groups (4 adenosine triphosphate and 2 guanosine

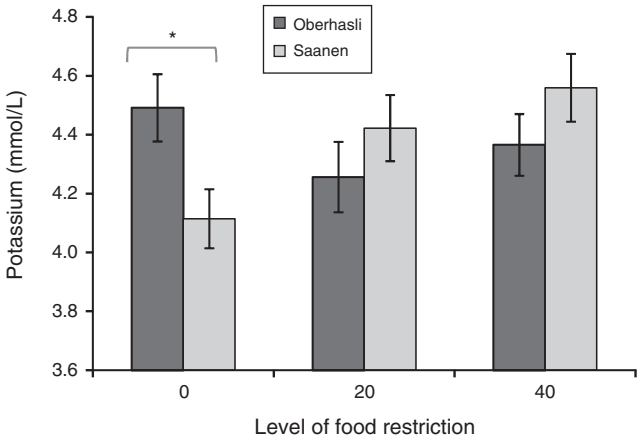

Fig. 3. Serum potassium levels (±s.e.m.) in Oberhasli and Saanen goats subjected to different feed restriction levels (0%, 20% and 40%) during pregnancy. *, $P < 0.05$.

triphosphate] to produce one glucose molecule from pyruvate (Lehninger *et al*. 2002). Therefore, P was possibly used for adenosine triphosphate formation in gluconeogenesis and low P amounts were available to the fetus and to the mammary gland of goats at 40% feed restriction.

Studies on sheep revealed that intrauterine feed restriction reduces the number of myofibrils formed in the fetus and DNA levels in the muscle, thereby decreasing postnatal growth (Greenwood *et al*. 2000; Estêvão *et al*. 2012). Therefore, we suggest that P reduction in the fetuses from goats at 40% of feed restriction may be related to the main cause of fetal growth delay observed, mainly due to the compromising of muscle development (Silva and Carvalho 2007). In addition, the higher retention of solids in the fetal fluid, exhibited in goats at 40% feed restriction, may be related to an inefficient nutrient use by the fetus. Given that, except for Na, mineral retention in the fetal fluid was not changed in our study; glucose levels in the fetal fluid were negligible (Tabatabaei 2011), the fetuses of ewes under nutritional deprivation had decreased soft tissue development (Luther *et al*. 2007), and fat growth in the fetuses did not decrease (Nguyen *et al*. 2010), we suggest that the fetuses may have wasted amino acids; these wasted amino acids increased with feed restriction and were possibly the primary components of the extra dry mass of solids detected in the fetal fluid of goats at 40% feed restriction. Furthermore, under ordinary conditions, Na levels in the fetal fluid are considered an indicator of fetal metabolism because the onset of renal activity in the fetus increases Na retention, with a consequent reduction in Na levels in the fetal fluid (Pearson and Mellor 1977; Tabatabaei 2011). As such, increased Na in the fetal fluid as a response to feed restriction may indicate damage to fetal metabolic functions.

Despite Na and K mobilisation from the MB, our results showed that the fetal Na and K accretion were not ensured and K retention in the mammary gland was also compromised. Therefore, we suggest that most of the Na and K obtained are likely used to meet maternal maintenance needs. In contrast to Ca, P and Mg, animals most likely do not have Na and K reserves, which are elements found abundantly in the diet

(Ammerman and Goodrich 1983; Suttle 2010). In addition, during gestation Na and K are required for functions such as absorptive nutrient processes in both the digestive tract and placenta, and to maintenance of the acid-base balance in the body (Suttle 2010). Thus, with a severe decrease in dietary mineral supply, the MB lacks reserves that can overcome Na and K deficiency and may not be able to avoid deprivation of these minerals in the fetus and mammary gland.

Irrespective of the feed restriction level imposed, the goats in the present study mobilised the Ca, P and Mg reserves accumulated at the beginning of pregnancy to meet uterus, fetal fluid, mammary gland, and in particular fetal nutrient demands. These results corroborate a study on dairy goats that reported a linear decrease in Ca, P and Mg retention in the MB as a function of advancing pregnancy (Härter *et al*. 2015). Moreover, we observed that goat body composition and serum Ca levels indicate that mobilisation of maternal reserves meet the growth needs of gestation products. A drop in serum Ca levels had previously been reported in pregnant goats at a more advanced pregnancy stage (100 days) (Yildiz *et al*. 2005). Concomitantly, ALP activity decreased after 95 days of gestation, indicating a reduction in osteoblastic activity and possible bone resorption in the MB. Studies on pregnant Saanen goats have revealed that specific ALP activity in the bones decreases linearly with fetal development and that bone mineral density declines from the last month of gestation onward (Liesegang *et al*. 2007). In this respect, determination of ALP activity seems to be an effective, practical and inexpensive method to identify bone mineral resorption only in cases of significant mineral mobilisation. However, for small amounts of Ca and P resorption, as observed in comparisons between days of pregnancy, ALP activity was not suitable for indicating bone mineral resorption.

Serum Mg levels were lower in Oberhasli goats, possibly because of higher Ca and P retention in the MB. Magnesium is important for parathyroid hormone formation and the bone tissue response to parathyroid hormone (Kronqvist *et al*. 2011). Therefore, Saanen goats, which have greater Ca and P mobilisation, may require higher Mg levels for parathyroid hormone production, particularly at the end of gestation when the Ca demand for fetal bone formation and colostrum production is higher. These results may suggest that Oberhasli and Saanen goats have different efficiencies in their bone Ca resorption metabolism. Differences in Mg metabolism were also observed in different cattle breeds (Greene *et al*. 1989) and sheep breeds (Field *et al*. 1969).

Differences in Na retention in the MB were also observed between the breeds tested in our experiment. Na is known to participate in water metabolism control, and it exhibits a close relationship with renal water absorption (Suttle 2010). Although Oberhasli goats did not have a greater amount of water in their MB, these goats had greater water amounts in the fetal fluid. Based on these observations we can suggest that these results may be related to adaptive adjustments of the Oberhasli goats' metabolism to different environments and more studies comparing the mineral metabolism of dairy goats are still needed.

Dairy goat breeds have been considered equally by international systems of animal feeding (NRC 2007). However, the differences between the mineral metabolism of Saanen and Oberhasli breeds shown in the present study indicate that they must be considered separately in feeding management plans. Saanen goats have higher milk production but a lower total solids concentration in milk than Oberhasli goats under similar environmental conditions (Haenlein 1996). Thus, these breeds likely have different metabolic processes, but comparative studies are still needed to fully understand the mechanisms underlying the different responses.

Conclusions

In response to the reduction in feed intake, the MB uses its mineral reserves to maintain gestation. Goats subjected to 20% feed restriction still support fetal growth; however, at 40% feed restriction P, Na, and K fetal accretion is impaired.

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