A comparative study on the excretion of urinary metabolites in goats and sheep to evaluate spot sampling applied to protein nutrition trials

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ABSTRACT: The main objective of this study was to establish a protocol to validate urine spot samples to estimate N excretion and microbial synthesis in goat and sheep; and to study factors that affect daily creatinine and purine derivatives (PD) urinary excretion. Also a performance trial was carried out to compare goat and sheep slaughtered after different feedlot periods. Twelve Boer goats (20.6 kg $\pm$ 3.4 initial BW) and 12 Dorper sheep (18.4 kg $\pm$ 2.3 initial BW), all 4-mo-old, males, were used. Eight animals (4 goats and 4 sheep) were randomly allocated to be slaughtered at 28, 56, and 84 d in feedlot. The experiment was conducted in a completely randomized design in a 2 $\times$ 3 factorial scheme, in which the factors were both species and the 3 feedlot periods. Diet consisted of 50% sorghum silage and 50% concentrate on a DM basis. Nutrient intake was higher ($P < 0.01$) for sheep than goats. Apparent digestibility of nutrients was similar ($P > 0.05$) in both species. Sheep had greater ($P < 0.01$) ADG and final BW than goats. Fat deposition and fat:muscle ratio was higher ($P < 0.01$) in sheep carcasses. Sheep had higher N urinary ($P = 0.02$) excretion and N retention (g/d; $P < 0.01$) than goats.

Urinary N excretion increased linearly ($P < 0.01$) in response to feedlot period. However, feedlot did not affect ($P = 0.20$) N retention, but linearly reduced the relationship between N retained and ingested ($P = 0.04$) or apparently digested ($P < 0.01$). Microbial efficiency ($P > 0.05$) did not differ between species. Creatinine excretion (C mg/d; $P < 0.01$) was higher in sheep than goats. Purine derivatives ($\hat{Y}$) were related closely with OM intake ($\hat{Y} = 0.013_{\pm 0.0007}X$; $r^2 = 94$). A difference ($P < 0.01$) was found between the allometric model for creatinine excretion ($\hat{Y}$) and muscle weight (X) for both species, and the following equations were obtained: $\hat{Y} = 89.04_{(\pm 31.44)}X^{0.9797(\pm 0.16)}$ for goats and $\hat{Y} = 109.8_{(\pm 47.50)}X^{0.8002(\pm 0.20)}$ for sheep. Creatinine concentration was greater during nocturnal than diurnal periods, with lower diurnal fluctuations. Sampling time did not affect ($P = 0.27$) the PD:C ratio. The urea (U):C ratio was higher ($P < 0.01$) in sheep than goats, and was also higher ($P < 0.01$) during diurnal than nocturnal sampling periods. Our results suggest that it is necessary to take 2 and 3 spot urine samples after feeding to estimate N compounds excretions in goats and sheep, respectively.

Key words: creatinine, fat, muscle, purine derivatives, spot urine, urea

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J. Anim. Sci. 2018.96:3381–3397
doi: 10.1093/jas/sky198

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Received January 23, 2018.

Accepted May 12, 2018.

INTRODUCTION

One of the main challenges in sheep and goat trials is to establish a rapid and noninvasive urine

collection protocol. The spot sampling technique is practical tool for studying the nitrogen urinary compounds, especially when total urine collection (24 h) is not feasible or time-consuming, e.g., under grazing conditions and/or for collections with lactating females in free stalls.

Creatinine excretion is more widely used as a tool to estimate daily urinary excretions in ruminant species. Although many studies have investigated this method for cattle (Valadares et al., 1999; Chizzotti et al., 2008), but a few have been conducted with sheep and goats (Chen et al., 1995; Santos et al., 2017). Santos et al. (2017) have reported that daily urinary creatinine excretion for growing goats is 17.39 mg/kg of BW, whereas David et al. (2015) indicate the value of 9.79 mg/kg of BW for adult sheep. Since creatinine is a muscle tissue metabolism by-product, we would not expect to find differences in creatinine excretions between species, mainly when BW is slightly different or similar. The fact that no comparative study has clearly established a collection protocol for the above small ruminant species is noteworthy.

Thus, we hypothesize that 1) sheep and goats do not present variations in creatinine excretions and muscle deposition for a same BW; 2) no differences in N intake, digestibility, and balance are observed between both species; 3) intake does not affect creatinine excretion, but affects purine derivative (PD) excretion; 4) spot samples can be taken to evaluate these species' protein nutritional status. The objective of this study was to establish a protocol to validate urine spot samples to estimate N excretion and microbial synthesis in goat and sheep; and to study factors that affect daily creatinine and PD urinary excretion. Also a performance trial was carried out to compare goat and sheep slaughtered after different feedlot periods.

MATERIALS AND METHODS

Animals, Experimental Design, and Diets

All the animal care and handling procedures were approved by the Ethics Committee on Animal Use of the School of Veterinary Medicine and Animal Science at the Federal University of Bahia, with protocol number 28-2014. The experiment was conducted at the Experimental Farm of the School of the same institution, located in the São Gonçalo dos Campos municipality, Bahia State, Brazil. Chemical analyses were performed at the Animal Nutrition Laboratory, also of the same institution, and at the Animal Physiology Laboratory at the Southwest State University of Bahia.

Twelve Boer goats, whose average initial BW was 18.4 ± 3.4 kg, and 12 Dorper sheep, whose average initial BW was 20.6 ± 2.3 kg, all males, not castrated and aged 4 mo, were used. Four animals of each species were subjected randomly to 1 of the 3 experimental treatments, which were 2 feedlot periods lasting 28, 46, and 84 d, which implied 8 animals per treatment. The experiment was conducted according to a completely randomized design and in a 2×3 factorial scheme, in which the factors were 2 species (goats and sheep) and the 3 feedlot periods (25, 46, and 84 d).

All the animals were housed in individual metabolic cages (total surface area of 1.2 m²), completely covered with a slatted floor, and equipped with individual feeders and water drinkers. Animals were submitted to a 15-d period to adapt to the experimental conditions, during which they were weighed, identified, and dewormed. Three experimental periods that lasted 28 d were carried out, of which the last 10 d of each period were used to sample all 8 animals, which were slaughtered on the last day. All the animals were weighed at the beginning and the end of each experimental period after a 16-h fasting period to measure the empty-body weight (EBW), total weight gain (TWG), and ADG.

The experimental isonitrogenous diet (150 g CP/kg DM) was formulated to provide an ADG of 200 g/d for sheep or goats according to NRC (2007). The chemical composition of the feed used in the experimental diets is shown in Table 1. The experimental diet consisted of 50% sorghum silage and 50% concentrate on a DM basis. The concentrate was a mixture of 681 g of ground corn/kg DM, 277.2 g of soybean meal/kg DM, 20 g of urea with ammonium sulfate (9:1)/kg of DM, and 21.8 g mineral mixture/kg DM (147.0 mg of sodium/kg DM; 120 mg of calcium/kg DM; 87 mg of phosphorus/

Table 1. Chemical composition of sorghum silage, concentrate, and diet

Chemical composition	Sorghum silage	Concentrate	Diet
DM, g/kg as fed basis	334.5	897.5	616.0
OM, g/kg DM	947.8	967.4	957.6
CP, g/kg DM	80.0	249.8	164.9
EE ¹ , g/kg DM	20.4	34.3	27.3
apNDF ² , g/kg of DM	530.3	8.1	269.2
Nonfibrous carbohydrates, g/kg of DM	314.8	655.6	565.9
iNDF ³ , g/kg of DM	251.0	22.1	136.5
Lignin, g/kg of DM	50.2	16.4	33.3

¹Ether extract.

²NDF corrected for ash and protein.

³Indigestible NDF.

kg DM; 18 mg of sulfur/kg DM; 3.8 mg of zinc/kg DM; 1.8 mg of iron/kg DM; 1.3 mg of manganese/kg DM; 0.59 mg of copper/kg DM of copper; 0.3 mg of molybdenum/kg DM; 0.08 mg of iodine/kg; 0.04 mg of cobalt/kg DM; 0.02 mg of chromium/kg DM; and 0.015 mg of selenium/kg DM). The experimental diet was offered to animals twice daily (0900 and 1600 h) in similar proportions. Daily intake was adjusted to keep leftovers between 10% and 20% of the offered daily amount of feed in wet basis.

Experimental Procedures and Sample Collection

Samples of the supplied sorghum silage and the orts of each animal were sampled daily throughout the experimental periods. They were submitted weekly to partial drying in a forced air ventilation oven (55 °C) for 72 h to obtain a composite sample. After drying, each sample was ground in a knife mill (Wiley mill; TECNAL, São Paulo, SP, Brazil) with 2 and 1 mm sieves, and was proportionally composited based on dry weight per animal and period. The concentrate ingredients were sampled directly from the grain storage of the feed factory in the days when they were mixed. Samples were stored for further chemical laboratory analyses.

Twelve spot urine samples were obtained from each animal during its respective slaughter period from day 18 to 19 of each experimental period, with 2-h intervals (0000, 0200, 0400, 0600, 0800, 1000, 1200, 1400, 1600, 1800, 2000, and 2200 h). Samples were obtained directly from collector funnels coupled to hoses, which conducted urine to plastic recipients. Subsamples were filtered through cheesecloth layers and 10-mL aliquots were filtered and diluted immediately with 40 mL of a 0.036 N sulfuric acid (H_2SO_4) solution (Valadares et al., 1999). Subsequently, a composite sample was obtained per sampling time based on the 2 sampling days to obtain 12 urine samples from each animal per period. Composite samples were stored at -20°C for further analyses of creatinine, DP (uric acid, allantoin, hypoxanthine and xanthine), and urea. Total urine volume was also recorded per animal, after taking into consideration all the spot volumes removed during the day. Total urine volume was used to estimate PD and urea daily excretions from each sampling time evaluated; and to compare it with the estimated urinary volume.

Six urine samples were obtained from each animal during its respective slaughter period from day 20 to 21 of each experimental period, which comprised a total of 4 h of total urine collection (0000 to 0400 h, 0400 to 0800 h, 0800 to 1200 h,

1200 to 1600 h, 1600 to 2000 h, 2000 to 0000 h). The total 4-h volume was recorded for each animal. Collector funnels coupled to hoses were used, which conducted urine to plastic containers with 100 mL of 20% H_2SO_4 . The procedures followed to dilute urine samples were similar to previously described ones. Subsequently, a composite sample was obtained per sampling time based on the 2 sampling days to obtain 6 urine samples per animal and period. Composite samples were stored at -20°C for further analyses.

Total urine collection was also done with the same animals, which were submitted to slaughter at the end of each period, from day 22 to 24 of each experimental period. Collector funnels coupled to hoses were used, which conducted urine to plastic containers with 100 mL of 20% H_2SO_4 . The urine volume was quantified at the end of each 24-h period, and subsamples were filtered through cheesecloth layers and immediately diluted with 40 mL of 0.036 N H_2SO_4 solution (Valadares et al., 1999). Urine samples were composited per period for each animal, and proportionally to the 3 sampling days. Composite samples were stored at -20°C for further analyses.

To evaluate nutrient digestibility, feces collection was organized from day 25 to 27 of each experimental period. Feces were collected on these 3 consecutive days (Lazzarini et al., 2016) every 16 h, which totaled 5 fecal samples per animal/period. Each sample was partially dried (55 °C for 72 h) and ground in a Wiley mill (TE-648, TECNAL, Piracicaba, Brazil) with 2 and 1 mm meshes, respectively. Feces samples were composited for each animal per period proportionally to the dry weight of all 5 samples. The indigestible NDF (iNDF) was used as a marker to estimate the total fecal excretion, after 288 h of ruminal incubation (Valente et al., 2015).

On day 28 of each experimental period, 8 animals (4 sheep and 4 goats) were subjected to a 16-h fasting period with free access to drink. Then, they were taken to be slaughtered in a commercial slaughterhouse, following all the necessary procedures to achieve humanitarian slaughtering. Animals were desensitized by cerebral concussion, followed by complete bleeding through the jugular section. After skinning and evisceration, carcasses were weighed immediately after slaughter and after being cooled to -4°C for 24 h to obtain the HCW and cold carcass weight (CCW). After these procedures, carcasses were split into 2 identical longitudinal halves, and the left half-carcass of each animal was dissected in the muscle, fat (subcutaneous and

intermuscular), and bones, and cartilages were removed. These samples were weighed to determine the proportions between these components in HCC and CCW.

Chemical Analyses

The samples of feeds, leftovers, and feces were analyzed for DM and mineral matter or ash (MM) following official methods 934.01 and 942.05 (AOAC, 2005), respectively. Organic matter was quantified by the difference between DM and MM contents. Total N was quantified according to official method 968.06 (AOAC, 2005). The residual NDF was corrected for ash and protein (apNDF) content by placing samples in 100-mL autoclavable flasks following the proportion of 1 g of sample per 100 mL of detergent (Mertens, 2002) with thermostable α -amylase (Novozymes A/S), and without adding sodium sulfite. These samples were autoclaved at 110 °C (Barbosa et al., 2015). The washing and filtration procedures for apNDF followed the protocol described by Barbosa et al. (2015). Lignin was measured according to official method 973.18 (AOAC, 2005) using 72% H_2SO_4 . The iNDF content was evaluated after an in situ incubation of the 2-mm ground samples for 288 h (Valente et al., 2015).

Creatinine was quantified in all the urine samples by the enzymatic method from an alkaline picrate reaction using a commercial kit for analysis purposes (creatinine - K016, Bioclin, Minas Gerais, Brazil). Urea was quantified in the urine samples by an enzymatic method in the presence of salicylate and sodium hypochlorite with a commercial kit (enzymatic urea - K047, Bioclin, Minas Gerais, Brazil). Allantoin, xanthine, and hypoxanthine were determined according to Chen and Gomez (1992). Uric acid was quantified by an enzymatic method in uricase and peroxidase with a commercial kit (monoreagent uric acid - K139, Bioclin, Minas Gerais, Brazil). The absorbed microbial purines and intestinal flow of microbial N were estimated from the equations proposed by Chen and Gomez (1992).

Statistical Analyses

The dependent variables were evaluated according to a completely randomized design in a 2×3 factorial scheme, using initial BW as a covariate, according to the model below:

$$Y_{ij} = \mu + \beta(X_{ij} - \bar{X}) + S_i + F_j + (SF)_{ij} + e_{ij}$$

where Y_{ij} = dependent variable measured in the experimental unit; μ = general mean; β = regression coefficient with the covariate; X_{ij} = the covariate observed value applied to the experimental unit; $\bar{X}$ = the mean value of the covariate; S_i = fixed effect of the species; F_j = fixed effect of feedlot period; $(SF)_{ij}$ = fixed effect of the interaction between species and feedlot period; e_{ij} = random error.

The ANOVA F -test was conclusive when comparing both species, whereas the data for feedlot time were compared by linear or quadratic orthogonal contrasts using the PROC MIXED of the SAS software (version 9.2), with a 5% probability level for the type I error occurrence. In case of significant interaction effect, the SLICE statement (SAS 9.2) was used to evaluate treatments means. The ANOVA F -test was conclusive when comparing both species within days in feedlot. Linear or quadratic orthogonal contrasts were used to compare days in feedlot within each species.

Data were evaluated in a time-repeated measures scheme for the specific case of the urine samples that corresponded to the 4-h intervals and the spot samples obtained every 2 h (Littell et al., 1998). The relationships of the dependent variables with collection times within the experimental units were interpreted by nonlinear regression. In the spot samples collected every 2 h, the interpretation of the creatinine:urea (U:C) and purine:creatinine derivatives (PD:C) ratios profile was made by a nonlinear Fourier series in a trigonometric polynomial scheme, as described by Detmann et al. (2007), with NLIN PROC of the SAS software (version 9.2).

$$Y_t = A_0 + \sum_{k=1}^k [A_k \sin(ckt) + B_k \cos(ckt)]$$

where Y_t are values of U:C and PD:C at sampling time t ; A_0 are the average estimates of U:C and PD:C; A_k and B_k are the parameters with no direct biological interpretation; c is the cycle (rad/h) of U:C and PD:C; k is the indexer that refers to the Fourier series, which ranges from 1 to K ; t is the sampling time. For both relations, the adjustment was made by considering $k = 1$ to 3, and the factor that allowed a significant adjustment was adopted. Thus, the fundamental period, calculated according to Detmann et al. (2007), is described as:

$$P = \frac{\pi}{c}$$

where P is the fundamental period during which the estimated movement resumed (hours).

The DM and OM intakes (g/kg of BW), BW (kg), CCW (kg), and the muscle weight (kg), as independent variables, were evaluated in relation to total creatinine excretion (mg/d or mg/kg BW) and with PD excretion (mmol/d and mmol/kg BW; dependent variables). Two basic models were fitted to describe these mathematical relationships, which were allometric and linear, either with or without the intercept. The intercept was not evaluated when the independent variables related to animals' BW were tested, as no biological significance was found for this value. These statistical procedures were performed with the SAS (Statistical Analysis System) program by procedures MIXED, REG, and NLIN, and by adopting 0.05 as the critical level of probability for the type I error.

The following model was used to estimate the parameters of the allometric curves of creatinine excretion in relation to BW, CCW, and muscle weight:

$$Y = D_1 \times (a_1 \times X^{b_1}) + D_2 \times (a_2 \times X^{b_2}) + T$$

where Y = creatinine excretion in mg/d; D_1 and D_2 are dummy variables that correspond to the goat and sheep species: $D_1 = 0$ and $D_2 = 1$ correspond to creatinine excretion in sheep, and $D_1 = 1$ and $D_2 = 0$ correspond to creatinine excretion in goats; a_1 and a_2 = intercept for goats and sheep, respectively; b_1 and b_2 = the exponential parameters for goats and sheep, respectively; X = the dependent variable.

The comparison made between the allometric model for goats and sheep was made using the identity test for nonlinear regression models, as described by Regazzi (1999). Restricted and full models were compared by the model identity test. In this case, different adjustments were made for each species. In the first adjustment, it was assumed that creatinine excretion was similar for both goats and sheep. The model that arose from this adjustment was called the "restricted model." In the second adjustment, these parameters were assumedly different for sheep and goats, and the model was called the "complete model." From this information, the statistical comparison was made using the χ^2 distribution as follows:

$$\chi^2_{\text{calc.}} = -n \times \ln \left(\frac{\text{RSS}_c}{\text{RSS}_r} \right)$$

where $\chi^2_{\text{calc.}}$ is the calculated value of the χ^2 statistics, n is the number of observations used to adjust creatinine excretion, RSS_c is the residual sum of the squares of the complete model, RSS_r is the residual sum of the squares of the restricted model, df is

the number of degrees of freedom used to perform the test, $p(c)$ is the number of parameters considered in the adjustment of the complete model, and $p(r)$ is the number of parameters considered in the adjustment of the restricted model. For all variables, $p(c) = 4$, $p(r) = 2$, and $df = 2$ were considered.

In order to obtain the nonlinear parameters, the Marquardt iterative algorithm was used, and the t statistics was used to construct the asymptotic confidence intervals for the parameters ($1 - \alpha = 0.95$) with the PROC NLIN program SAS (version 9.2).

The linear adjustments using creatinine or PD as the independent variables (Y), and DM and OM intakes, BW, CCW, and muscle weight as the dependent variables (X), were made by a multiple linear regression model:

$$Y = \beta_0 + \beta_1 D_1 + \beta_2 X + \beta_3 (X \times D_1) + e$$

where D_1 is a dummy variable that corresponds to the effects of the studied species, $D_1 = 0$ for goats and $D_1 = 1$ for sheep. Finally, 5% was used as the critical level of probability for the type I error. The analysis was run using PROC REG of SAS. After these analyses, the proposed equation was used to calculate the total creatinine excretion (mg/d) and urinary volume (liter/d) for each animal, and these values were compared with those quantified in total urinary volume, using the Dunnett test with 5% as the critical level of probability for the type I error.

RESULTS

Digestibility, Performance, Carcass Characteristics, and Microbial Synthesis

There was no interaction ($P > 0.05$) between species and feedlot days for any of the studied nutrient intake and digestibility variables (Table 2). Nutrient intake (kg or g/kg BW) was higher ($P < 0.01$) for sheep than for goats. Feedlot days ($P > 0.05$) had no effect on DM intake and the other dietary constituents (kg/d). However, nutrient intake linearly reduced ($P = 0.02$) when expressed as g/kg BW. Digestibility of DM and other dietary constituents did not differ ($P > 0.05$) between sheep and goats.

There was no interaction ($P > 0.05$) between species and feedlot days for any of the studied performance variables (Table 3). Sheep had greater ($P < 0.01$) ADG and final BW than goats. Muscle (kg; $P = 0.60$) and bone (kg; $P = 0.64$) content did not differ between species. However, as CCW proportions, goats had higher muscle ($P < 0.01$) and bone ($P < 0.01$) contents (%) than sheep. The

Table 2. Effect of animal species and feedlot period on nutrient intake and nutrient apparent digestibilities

Item	Species		Days in feedlot			SEM	P value ¹		
	Goat	Sheep	28	56	84		Species	DF	S × DF
Intake (kg/d)									
DM	0.79	1.12	0.90	0.94	1.03	0.04	<0.01	0.13	0.80
OM	0.76	1.07	0.86	0.90	0.99	0.04	<0.01	0.11	0.79
CP	0.13	0.20	0.17	0.16	0.16	0.01	<0.01	0.76	0.72
apNDF ²	0.25	0.35	0.30	0.28	0.31	0.01	<0.01	0.26	0.82
NFC ³	0.36	0.50	0.39	0.43	0.48	0.02	<0.01	0.22	0.88
TDN	0.60	0.85	0.71	0.68	0.77	0.03	<0.01	0.35	0.45
Intake (g/kg of BW) ⁴									
DM	33.70	43.47	42.21	36.48	37.07	1.56	<0.01	0.02	0.34
apNDF	10.63	13.43	14.09	10.83	11.16	0.54	<0.01	<0.01	0.23
Digestibility (g/kg) ⁵									
DM	650	694	674	707	703	4.71	0.89	<0.01	0.42
OM	715	714	693	724	727	4.79	0.89	<0.01	0.13
CP	723	726	697	733	744	7.43	0.77	0.01	0.12
apNDF	505	497	498	497	510	10.60	0.72	0.84	0.11
NFC	841	853	820	862	859	7.27	0.44	0.04	0.85
TDN	716	716	695	722	730	5.02	0.99	<0.01	0.10

¹DF = days in feedlot; S × DF = interaction between animal species and days in feedlot.

²NDF corrected for ash and protein.

³Nonfibrous carbohydrates.

⁴DM = linear effect: $P = 0.02$ and quadratic effect: $P = 0.09$; apNDF: linear effect: $P < 0.01$ and quadratic effect: $P < 0.01$.

⁵DM: linear effect: $P = 0.01$ and quadratic effect: $P = 0.05$; OM: linear effect: $P < 0.01$ and quadratic effect: $P = 0.11$; CP: linear effect: $P < 0.01$ and quadratic effect: $P = 0.32$; NFC: linear effect: $P = 0.03$ and quadratic effect: $P = 0.13$; TDN: linear effect: $P < 0.01$ and quadratic effect: $P = 0.21$.

Table 3. Effect of animal species and feedlot period on growth performance and carcass tissue composition

Item	Species		Days in feedlot			SEM	P value ¹		
	Goat	Sheep	28	56	84		Species	DF	S × DF
Performance ² (kg)									
Final BW	27.44	31.43	23.75	29.75	34.81	1.40	<0.01	<0.01	0.20
Weight total gain	7.74	11.73	4.05	10.05	15.11	1.23	<0.01	<0.01	0.20
ADG	0.10	0.16	0.09	0.14	0.16	0.01	<0.01	<0.01	0.34
HCW	12.87	14.55	11.05	13.25	16.83	0.71	0.01	<0.01	0.62
CCW ³	12.78	14.47	10.98	13.26	16.64	0.70	0.01	<0.01	0.58
Weight of tissue (kg) ⁴									
Muscle	7.74	8.08	7.08	7.81	8.83	0.37	0.60	0.10	0.28
Fat	1.15	2.51	1.23	1.69	2.57	0.21	<0.01	<0.01	<0.01
Bone	2.62	2.68	2.20	2.64	3.11	0.11	0.64	<0.01	0.44
Tissue ratio									
Muscle:bone	2.82	3.04	2.94	2.95	2.90	0.10	0.13	0.94	0.43
Fat:bone	0.43	0.91	0.55	0.63	0.83	0.03	<0.01	<0.01	<0.01
Fat:muscle	0.16	0.30	0.19	0.21	0.28	0.007	<0.01	<0.01	<0.01
Weight of tissue (% CCW) ⁵									
Muscle	66.14	61.43	65.49	64.49	61.38	0.73	<0.01	<0.01	0.92
Fat	10.27	18.19	12.09	13.64	16.95	0.98	<0.01	<0.01	<0.01
Bone	23.58	20.36	22.40	21.85	21.66	0.52	<0.01	0.76	0.27

¹DF = days in feedlot; S × DF = interaction between animal species and days in feedlot.

²Final BW: linear effect: $P < 0.01$ and quadratic effect: $P = 0.64$; weight total gain: linear effect: $P < 0.01$ and quadratic effect: $P = 0.64$; ADG: linear effect: $P < 0.01$ and quadratic effect: $P = 0.27$; HCW: linear effect: $P < 0.01$ and quadratic effect: $P = 0.29$; CCW: linear effect: $P < 0.01$ and quadratic effect: $P = 0.37$.

³CCW = cold carcass weight.

⁴Bone: linear effect: $P < 0.01$ and quadratic effect: $P = 0.85$.

⁵Muscle: linear effect: $P < 0.01$ and quadratic effect: $P = 0.70$.

proportions of muscle in CCW linearly lowered ($P < 0.01$) in response to feedlot days.

There was an interaction ($P < 0.01$) between species and feedlot days in fat content (expressed as kg or % of CCW). The interaction slice showed that fat deposition in both species linearly increased ($P < 0.01$) in response to feedlot days. Sheep presented higher fat content deposition ($P < 0.01$) than goat (Table 4). There was an interaction ($P < 0.05$) between species and feedlot days with the fat:bone and fat:muscle ratios. Both ratios linearly increased ($P < 0.01$) in response to feedlot days, and were lower in goats than in sheep.

There was no interaction ($P > 0.05$) between species and feedlot days for the studied N compounds balance and microbial synthesis variables (Table 5). Sheep had higher N fecal ($P < 0.01$) and N urinary ($P = 0.02$) excretion and N retention (g/d; $P < 0.01$). However, the relationships between N retained and N ingested ($P = 0.38$) or apparently digested ($P = 0.34$) did not differ between sheep and goats.

Urinary N excretions linearly increased ($P < 0.01$) in response to increasing feedlot days (Table 5). Feedlot days did not affect ($P = 0.20$) N retention, but linearly reduced the relationships between N retained and N ingested ($P = 0.04$) or apparently digested ($P < 0.01$). Sheep showed a higher ($P = 0.01$) microbial crude protein (MCP) synthesis than goats. However, the microbial efficiency in relation to digestible OM ($P = 0.29$) or TDN ($P = 0.29$) did not differ between species. Feedlot days affected neither MCP synthesis

($P = 0.78$) nor microbial efficiency in relation to digestible OM ($P = 0.86$) or TDN ($P = 0.87$).

Purine Derivatives, Creatinine, Urea, PD:C and U:C Ratios

Sheep had higher daily urinary excretion of allantoin ($P = 0.01$), uric acid ($P < 0.01$), xanthine and hipoxanthine ($P < 0.01$) than goats (Table 6). Similarly, total PD excretion (mmol/d) was higher ($P < 0.01$) in sheep (6.67 mmol/d) than in goats (11.58 mmol/d). Excretions of creatinine (mg/d; $P < 0.01$) and urea N (g/d; $P = 0.04$), estimated from the total urine collection, were higher by approximately 24 and 43.8%, respectively, in sheep compared with goats.

The regression equations demonstrated that PD was closely related with DMI and OM intake (Table 7; Figure 1). Considering that no differences were found between sheep and goats, a single equation was obtained between PD ($\hat{Y}$, expressed in mmol/d) and DM (X , expressed in g/kg BW): $\hat{Y} = 0.009 \pm 0.0005X$ ($r^2 = 0.82$) and PD ($\hat{Y}$, mmol/d) to OM (X , expressed in g/kg BW): $\hat{Y} = 0.013 \pm 0.0007X$. Intercepts were not significant both for DM ($P = 0.48$) or OM ($P = 0.37$) intake adjustments. When relating PD ($\hat{Y}$, expressed in mmol/d) and BW, CCW, and weight muscle (X , expressed in kg), no difference ($P > 0.05$) on the slope was observed, which suggests that these parameters did not influence PD excretion.

No difference ($P > 0.05$) was observed on the slope of the regressions between urinary creatinine excretion ($\hat{Y}$, expressed in mmol/d), and DM or OM intake (X , expressed in g/kg BW). However, the regression equations demonstrated that creatinine excretion was closely related with BW, CCW, and weight muscle. No differences were found between sheep and goats when considering the relationship of creatinine according to BW ($P = 0.18$) and CCW ($P = 0.16$). When relating creatinine ($\hat{Y}$, mmol/d) to BW (X , kg/d) and CCW (X , kg/d), the equations were, respectively, $\hat{Y} = 19.82 (\pm 1.49)X$ ($r^2 = 0.98$) and $\hat{Y} = 45.25 (\pm 1.32)X$ ($r^2 = 0.98$) (Figure 2). The relationship of creatinine ($\hat{Y}$, mmol/d) with muscle weight (X , kg/d) showed a difference ($P < 0.01$) between species, and a separate linear equation was obtained: $\hat{Y} = 71.75 (\pm 2.78)X$ for goats and $\hat{Y} = 85.25 (\pm 4.03)X$ for sheep.

The allometric model showed no difference ($P > 0.05$) between species for the relationship of creatinine excretion ($\hat{Y}$, expressed in mmol/d) to BW or CCW (X , expressed as kg) (Table 8). Thus, the following allometric equations that

Table 4. Effects of interactions slicing between animal species and days in feedlot in relation the fat weight and fat:bone and fat:muscle ratios

Item ¹	Days in feedlot			P value	
	28	56	84	Linear	Quadratic
Fat (kg)					
Goat	0.91	1.17	1.64	<0.01	0.27
Sheep	1.53	2.17	3.49	<0.01	0.26
Fat:bone					
Goat	0.39	0.45	0.51	<0.01	0.82
Sheep	0.70	0.80	1.14	<0.01	0.32
Fat:muscle					
Goat	0.13	0.15	0.19	<0.01	0.28
Sheep	0.23	0.27	0.36	<0.01	0.20
Fat (% cold carcass weight)					
Goat	9.24	10.32	12.32	<0.01	0.23
Sheep	14.92	16.98	21.54	<0.01	0.26

¹Slicing procedure resulted of significant interaction effects in variables evaluated in Table 3.

Table 5. Effect of animal species and feedlot period on nitrogen (N) balance, microbial CP synthesis, and its efficiency

Item	Species		Days in feedlot			SEM	P value ¹		
	Goat	Sheep	28	56	84		Species	DF	S × DF
Nitrogen balance									
N fecal, g/d	6.12	8.97	8.48	7.56	6.59	0.41	<0.01	0.18	0.26
N urinary ² , g/d	5.23	7.28	4.19	6.84	7.73	0.62	0.02	<0.01	0.30
N intake, g/d	21.1	32.1	27.7	25.8	26.4	1.38	<0.01	0.70	0.68
N retained, g/d	9.83	15.91	15.09	11.39	12.13	0.94	<0.01	0.20	0.59
N retained ³ , % do N intake	45.04	49.19	54.89	42.46	43.99	2.15	0.38	0.04	0.38
N retained ⁴ , % do N apparently absorbed	63.24	68.60	78.50	60.43	58.83	2.83	0.34	<0.01	0.87
Microbial protein									
Microbial CP, g/d	34.68	59.12	47.40	43.30	49.95	6.42	0.01	0.78	0.61
Microbial efficiency									
g microbial CP/OM digestible	60.01	71.01	68.07	61.71	66.75	7.86	0.29	0.86	0.62
g microbial CP/TDN	57.31	67.95	65.08	59.11	63.72	7.52	0.29	0.87	0.63

¹DF = days in feedlot; S × DF = interaction between animal species and days in feedlot.

²N urinary: linear effect: $P < 0.01$ and quadratic effect: $P = 0.20$.

³N retained, % do N intake: linear effect: $P = 0.07$ and quadratic effect: $P = 0.13$.

⁴N retained, % do N apparently absorbed: linear effect: $P = 0.01$ and quadratic effect: $P = 0.13$.

Table 6. Effect of animal species and feedlot period on excretion of urinary purine derivatives, creatinine, urea, and nitrogen compounds measured from total 24-h urine collections

Item	Species		Days in feedlot			SEM	<i>P</i> value ¹		
	Goat	Sheep	28	56	84		Species	DF	S × DF
Purine derivatives ² (mmol/dia)									
Allantoin, mmol/d	5.83	9.22	7.83	7.15	7.59	0.98	0.01	0.90	0.74
Acid uric, mmol/d	0.39	1.49	1.19	0.69	0.93	0.15	<0.01	0.15	0.35
Xant. and hipoxant, mmol/d ³	0.44	0.85	0.53	0.56	0.85	0.05	<0.01	<0.01	0.94
Total PD, mmol/d ⁴	6.67	11.58	9.55	8.40	9.40	1.05	<0.01	0.74	0.82
Total PD, mmol/kg BW	0.23	0.34	0.34	0.26	0.24	0.03	0.01	0.14	0.77
Total PD, mmol/ kg BW ^{0.75}	0.54	0.83	0.81	0.63	0.60	0.07	<0.01	0.15	0.87
Creatinine ⁵									
mg/d	558.2	691.8	515.3	625.0	734.6	32.90	<0.01	<0.01	0.70
mg/kg BW	19.20	20.40	19.60	20.30	19.40	2.50	0.34	0.81	0.97
mmol/kg BW ^{0.75}	0.39	0.43	0.39	0.42	0.42	6.45	0.17	0.53	0.96
Urea									
g/d	4.20	6.04	5.05	4.91	5.41	0.88	0.04	0.87	0.89
mg/kg BW	166.8	181.3	209.6	162.9	149.6	27.30	0.53	0.12	0.41
mg/kg BW ^{0.75}	375.4	427.4	466.3	379.1	358.7	64.80	0.35	0.25	0.37
Total nitrogen compounds ⁶									
g/d	5.23	7.28	4.20	6.85	7.72	0.62	<0.01	<0.01	0.30
mg/kg BW	185.4	215.4	159.7	221.5	219.9	16.34	0.22	<0.01	0.61
mg/kg BW ^{0.75}	425.3	517.7	360.64	521.9	532.2	38.95	0.10	<0.01	0.52

¹DF = days in feedlot; S × DF = interaction between animal species and days in feedlot.

²Xanthine and hipoxanthine: linear effect: $P < 0.01$ and quadratic effect: $P = 0.08$.

³Xant. and Hipoxant = xanthine and hipoxanthine.

⁴PD = purine derivatives.

⁵Creatinine (mg/d): linear effect: $P < 0.01$ and quadratic effect: $P = 0.99$.

⁶Total nitrogen compounds (g/d): linear effect: $P < 0.01$ and quadratic effect: $P = 0.73$; total nitrogen compounds (mg/kg BW): linear effect: $P < 0.01$ and quadratic effect: $P = 0.32$; total nitrogen compounds (mg/kg BW^{0.75}): linear effect: $P < 0.01$ and quadratic effect: $P = 0.38$.

considered BW and CCW were suggested for both species, respectively: $\hat{Y} = 15.8 (\pm 7.23)X^{1.064(\pm 0.13)}$; $\hat{Y} = 65.19 (\pm 22.27)X^{0.8643(\pm 0.13)}$. A difference

($P < 0.01$) was found between the allometric equation for creatinine ($\hat{Y}$, mmol/d) and muscle weight (X , kg/d) for goats and sheep, when a separate

Table 7. Estimated parameters for linear regression between excretions of urinary creatinine or purine derivatives as a function of DMI, OM intake, BW, cold carcass weight (CCW), and muscle weight

Linear regression	Full model				Restricted model			
	Goat, mmol/kg		Sheep, mmol/kg		Goat and sheep, mmol/kg			
	Intercept	Slope	Intercept	Slope	P value ¹	Intercept ²	Slope ²	r ²
Purine derivatives as a function of:								
DMI (g/kg BW)	—	0.0078 ± 0.0073	—	0.0095 ± 0.0095	P = 0.82	—	0.0089 ± 0.0005	0.94
OMI (g/kg BW)	—	0.011 ± 0.0010	—	0.013 ± 0.0014	P = 0.08	—	0.013 ± 0.0007	0.08
BW (kg)	6.94 ± 5.26	—	12.56 ± 6.67	—	P = 0.41	7.33 ± 4.18	—	0.50
CCW (kg)	7.38 ± 4.70	—	13.45 ± 5.80	—	P = 0.31	9.36 ± 3.65	—	0.08
Weight muscle (kg)	6.58 ± 4.79	—	12.84 ± 6.13	—	P = 0.32	10.67 ± 3.99	—	0.10
Creatinine as a function of:								
DMI (g/kg BW)	18.03 ± 3.00	—	21.11 ± 3.99	—	P = 0.45	17.05 ± 1.66	—	0.32
OMI (g/kg BW)	17.35 ± 3.11	—	21.19 ± 4.25	—	P = 0.37	16.65 ± 1.74	—	0.33
BW (kg)	—	19.11 ± 1.70	—	20.45 ± 1.96	P = 0.18	—	19.82 ± 1.49	0.98
CCW (kg)	—	43.27 ± 1.86	—	47.06 ± 2.58	P = 0.16	—	45.247 ± 1.32	0.98
Weight muscle (kg)	—	71.75 ± 2.78	—	85.25 ± 4.03	P < 0.01	—	—	0.98

¹P value obtained by binary comparison of the fit of a single or double linear regression model.

²Significant parameters ($P < 0.05$) were maintained in the adjusted equations, where a = intercept ± SE and b = slope ± SE. In the case of nonsignificant parameters, the symbol (—) was used.

Figure 1. Purine derivative (PD) excretion ($\hat{Y}$, expressed in mmol/d) in the urine of sheep and goats as a function of DMI (X , expressed in g/kg BW): $\hat{Y} = 0.009 \pm 0.0005X$ ($r^2 = 0.82$). **Figure 2.** Creatinine ($\hat{Y}$, mmol/d) in the urine of sheep and goats as a function of shrunk BW (X , kg): $\hat{Y} = 19.82 (\pm 1.49)X$ ($r^2 = 0.98$).**Table 8.** Estimated parameters for allometric regression between excretion of urinary creatinine (mg/d) as a function of BW, cold carcass weight, and muscle weight

	Body weight, kg
Goat	$\hat{Y} = 17.28 (\pm 10.56) X^{1.0472 (\pm 0.17)}$
Sheep	$\hat{Y} = 22.22 (\pm 17.37) X^{0.9563 (\pm 0.23)}$
Goat and sheep	$\hat{Y} = 15.8 (\pm 7.23) X^{1.064 (\pm 0.13)}$
	$P = 0.37$
	Cold carcass weight, kg
Goat	$\hat{Y} = 74.48 (\pm 42.76) X^{0.7939 (\pm 0.22)}$
Sheep	$\hat{Y} = 76.69 (\pm 31.81) X^{0.9221 (\pm 0.15)}$
Goat and Sheep	$\hat{Y} = 65.19 (\pm 22.27) X^{0.8643 (\pm 0.13)}$
	$P = 0.15$
	Weight of muscle, kg
Goat	$\hat{Y} = 89.04 (\pm 31.44) X^{0.9797 (\pm 0.16)}$
Sheep	$\hat{Y} = 109.8 (\pm 47.50) X^{0.8002 (\pm 0.20)}$
Goat and Sheep	$P < 0.01$

Equations obtained by comparison of nonlinear fit of a single or double allometric regression model using the X^2 , or model identity test (Regazzi et al., 1999); and the significant parameters ($P < 0.05$) were maintained in the adjusted equations.

allometric equation was obtained: $\hat{Y} = 89.04 (\pm 31.44) X^{0.9797 (\pm 0.16)}$ for goats and $\hat{Y} = 109.8 (\pm 47.50) X^{0.8002 (\pm 0.20)}$ for sheep.

There was no interaction ($P > 0.05$) among species, feedlot days and sampling time for the evaluated urinary excretion of creatinine, PD, urea, and the PD:C or U:C ratios (Table 9). Creatinine excretion, expressed in mg/d ($P = 0.93$), mg/kg BW ($P = 0.16$), and mmol/kg BW 0.75 ($P = 0.29$), did not differ ($P = 0.93$) between species.

The creatinine excretion obtained during the total 4-h urine collection was not affected by sampling time. However, the creatinine concentration was higher during the nocturnal (1800 to 0600 h) than the diurnal (0600 to 1800 h) intervals (Figure 3). Creatinine also showed few diurnal fluctuations.

Sampling time affected ($P = 0.02$) urinary PD excretions, which was longer during the diurnal period for both species (Table 10). However, sampling time did not affect the PD:C ratio obtained from the total 4-h urine collection with ($P = 0.76$) and the spot collection done every 2 h ($P = 0.27$) (Table 11).

Table 9. Effect of animal species and feedlot period on excretion of urinary creatinine, purine derivatives, and urea obtained from total collections after 4-h intervals

Item ¹	Species		Days in feedlot			SEM	<i>P</i> value ¹						
	Goat	Sheep	28	56	84		Species	DF	T	S × DF	S × T	DF × T	S × DF × T
Creatinine ²													
mg/d	170.56	168.74	117.36	190.63	166.14	8.51	0.93	<0.01	0.27	0.62	0.23	0.46	0.07
mg/kg BW	6.05	5.31	5.05	6.50	5.48	0.25	0.16	0.07	0.41	0.72	0.43	0.51	0.17
mmol/kg BW ^{0.75}	0.10	0.09	0.08	0.11	0.10	0.01	0.29	0.04	0.39	0.74	0.38	0.50	0.13
Purine derivatives ³													
mmol/d	1.55	2.10	1.55	1.73	2.20	0.11	0.01	0.04	0.02	0.64	0.01	0.18	0.08
mmol/kg BW ^{0.75}	0.13	0.16	0.15	0.14	0.15	0.01	<0.01	0.63	0.02	0.07	0.03	0.18	0.06
Urea ⁴													
g/d	0.71	1.03	0.63	0.97	1.00	0.05	<0.01	<0.01	0.03	0.65	0.52	0.14	0.18
mg/kg BW	24.72	34.13	28.12	32.54	27.62	1.45	<0.01	0.38	0.02	0.24	0.61	0.10	0.11
Ratios													
PD:C ⁵	1.60	2.19	1.99	2.01	1.68	0.09	<0.01	0.31	0.76	0.32	0.82	0.68	0.12
U:C ⁶	3.90	5.74	4.50	5.59	4.37	0.21	<0.01	0.06	0.01	<0.01	0.96	0.45	0.44

¹DF = days in feedlot; T = time of sampling comprising 4-h urinary collections along the day; S × DF = interaction between animal species and days in feedlot; DF × T = interaction between days in feedlot and time of sampling; S × DF × T = interaction between species, days in feedlot, and time of sampling.

²Creatinine (mg/d): linear effect: $P = 0.02$ and quadratic effect: $P = 0.14$; creatinine (mmol/kg BW^{0.75}): linear effect: $P = 0.13$ and quadratic effect: $P = 0.04$.

³Purine derivatives (mmol/d): linear effect: $P = 0.01$ and quadratic effect: $P = 0.50$.

⁴Urea (g/d): linear effect: $P < 0.01$ and quadratic effect: $P = 0.18$.

⁵PD:C = purine derivatives:creatinine ratio.

⁶U:C = urea:creatinine ratio.

Figure 3. Observed means of the daily fluctuation in creatinine concentrations, according to sampling time with 2-h intervals for spot urinary collection; and observed mean of creatinine concentration from 24-h total collection, with its respective confidence interval ($\alpha = 95\%$), evaluated in Dorper sheep and Boer goats.

Table 10. Effect of sampling time on excretion of urinary creatinine, purine derivatives, and urea obtained from total collections after 4-h intervals

Item ¹	Time of sampling (h)						SEM
	0000 to 0400	0400 to 0800	0800 to 1200	1200 to 1600	1600 to 2000	2000 to 0000	
Creatinine, mg	201.65	162.79	144.03	166.14	190.76	152.29	8.51
Creatinine, mg/kg BW	6.47	5.50	4.84	5.75	6.29	5.19	0.25
Creatinine, mmol/kg BW ^{0.75}	0.11	0.09	0.08	0.09	0.11	0.09	0.01
PD, mmol ¹							
Goat	1.13Bb	1.74a	1.11Bb	2.46a	1.30Bb	1.54b	0.13
Sheep	2.54Aa	1.49b	2.51Aa	2.53a	2.17Aa	1.34b	0.15
PD, mmol/kg BW ^{0.75}							
Goat	0.09Bb	0.14b	0.09Bb	0.19a	0.11b	0.13b	0.01
Sheep	0.19Aa	0.12b	0.17Aa	0.20a	0.17a	0.11b	0.01
Urea, g/d	0.68b	0.92a	0.82b	1.14a	0.89b	0.74b	0.05
Urea, mg/kg BW	21.66b	30.35b	26.71b	39.13a	30.81b	27.66b	1.45
PD:C ²	1.67	1.80	1.84	2.06	1.99	2.00	0.09
U:C ³	3.49b	4.76b	5.01a	5.99a	4.74b	4.90a	0.21

¹PD = purine derivatives.²PD:C = purine derivatives:creatinine ratio.³U:C = urea:creatinine ratio.**Table 11.** Purine derivatives:creatinine and urea:creatinine ratios obtained from spot collections after 2-h intervals

Item	Species		Days in feedlot				P value ¹						
	Goat	Sheep	28	56	84	SEM	Species	DF	T	S × DF	S × T	DF × T	S × DF × T
PD:C ²	1.86	3.74	3.85	2.32	2.24	0.81	<0.01	0.09	0.27	<0.01	0.58	0.93	0.91
U:C ³	3.62	10.17	7.30	5.43	7.95	0.75	<0.01	<0.01	<0.01	<0.01	0.04	0.10	0.25

¹DF = days in feedlot; T = time of sampling; S × DF = interaction between animal species and days in feedlot; S × T = interaction between animal species and time of sampling; DF × T = interaction between days in feedlot and time of sampling; S × DF × T = interaction between species, days in feedlot and time of sampling.

²PD:C = purine derivatives:creatinine ratio.³U:C = urea:creatinine ratio.

The U:C ratio estimated from the spot urine sampling at 2-h intervals ($P < 0.01$) followed the same pattern as that for the total 4-h urine collection ($P < 0.01$), which was higher in sheep than in goats. Sheep also presented a higher U:C ratio than goats, and this ratio was higher ($P < 0.01$) during the diurnal period (in the spot urine sampling with 2-h intervals) than the nocturnal period for both species ($P < 0.01$) (Table 12). The temporal variability of the U:C ratios in both goats and sheep are shown in Figure 4. In goats, the mathematical function adjusted was $\hat{Y} = 3.71 + (-0.03 \times \text{SEN}(-0.2572 \times t))$, where 3 daily points were estimated close to the mean, with a fundamental period estimated at 12.2 h to complete each cycle ($P < 0.01$). In sheep, this function presented 2 daily points that came close to the mean, through the equation: $\hat{Y} = 10.67 + (0.15 \times \text{SEN}(-0.2389 \times t))$ with an estimated fundamental period of 13.1 h ($P < 0.01$) to repeat the estimated standard.

The estimated urinary volumes obtained from all spot samples of daylong (Figure 5) did not differ ($P > 0.05$) from that observed in total urine collection, with exception for the 0-h ($P = 0.02$) time point. The PD excretion estimated from spot samples differed from the observed mean in times 0, 2, 4, 6, 8, and 10 h ($P < 0.05$). The other daytime spot samples were similar to that from observed urinary volume ($P > 0.05$). The urea excretion estimated from all spot samples of daylong (Figure 5) did not differ ($P > 0.05$) from that observed.

DISCUSSION

Digestibility, Performance, Carcass Characteristics, and Microbial Synthesis

In general, the results of this study confirm differences in nutrient intake between the goats and sheep fed a similar diet. In a comparative study using

Table 12. Effect of species and sampling time on purine derivatives:creatinine and urea:creatinine ratios obtained from spot collection after 2-h intervals

Time of sampling (h)	PD:C ¹	U:C ²	
		Goat	Sheep
0000	1.40	2.81	4.67
0200	1.37	1.86	6.89
0400	2.70	3.98	11.67
0600	2.23	3.92	8.48
0800	3.37	5.16	13.70
1000	2.69	3.83	9.28
1200	3.15	3.72	16.11
1400	2.45	3.30	9.83
1600	2.64	5.23	14.83
1800	2.39	3.02	12.01
2000	2.34	3.61	6.84
2200	2.04	2.97	7.73
SEM	1.13	1.47	1.58
<i>P</i> value ³			
Time of sampling	0.27	<0.01	<0.01
S × T	0.58	0.04	0.04

¹PD:C = purine derivatives:creatinine ratio.

²U:C = urea:creatinine ratio.

³S × T = interaction between species and time of sampling.

goats and sheep fed a hay-based diet, [Domingue et al. \(1991a\)](#) have reported that goats spent more time eating (3 h) and presented a lower (62%) eating rate (DM intake per minute), which may justify the differences in intake observed between both species. Other studies have confirmed that goats spend more time selecting the more nutritious parts of forage than sheep ([Lindberg and Gonda, 1996](#); [Animut and Goetsch, 2008](#)). Our results suggest that the lower intake of goats vs. sheep is partly due to the longer time spent on selecting dietary nutrients. Considering that sheep are categorized as typical grazers and goats represent an intermediate group of mixed feeders, while sheep present a greater reticulo-rumen according to body size than goats ([Van Soest, 1994](#); [NRC, 2007](#)), we can expect greater DM and fiber intake according to BW in sheep.

In spite of the low nutrient intake found for goats, no differences in the apparent digestibility of nutrients between goats and sheep were found. It has been recognized that digestion of nutrients differs between ruminant species depending on forage quality ([Soto-Navarro et al., 2014](#)). Several studies have reported that sheep and goats fed with high quality forage present an apparently similar digestibility of nutrients ([Carro et al., 2012](#); [Askar et al., 2016](#)). Other studies have shown that goats vs. sheep are more efficient at digesting nutrients

when fed forage composed of a low CP and high fiber content, which is typical of tropical conditions ([Domingue et al., 1991b](#); [Askar et al., 2016](#)). It is noteworthy that both animals in the present study ate the same diet composed of sorghum silage as forage. Thus, when considering that no differences appeared in the quality of the diets offered to both ruminant species, our results suggest that sheep and goats have a similar capacity to digest diets that consist in sorghum silage as forage.

It has been recognized that factors, such as substrate availability and synchronization in the rumen, are important factor and influence the usage efficiency of ruminal substrates ([Ipharraguerre et al., 2005](#)). Despite the lower nutrient supply in ruminal environments, goats presented similar microbial efficiency than sheep. These facts can be attributed to the differences between ruminant species in their ability to recycle N in the rumen. Considering that N recycling appears more extended for goats than sheep ([Asmare et al., 2012](#)), this event may ensure adequate synchronization between protein and energy for microbial growth.

Once that the intake is an important factor that influences performance ([Riaz et al., 2014](#); [Dórea et al., 2017](#)), we expected greater intake to result in greater daily body gain (average = 160 g/d) and slaughter weight (average = 31.43) in sheep than in goats (average = 100 g/d; 27.44 kg, respectively). [Mahgoub and Lodge \(1998\)](#) have reported a greater daily gain in sheep (179 g/d) than in goats (111 g/d). These authors have also emphasized that the mean age at which sheep reach predetermined slaughter weight (120 d; 22.3 kg) is younger than goats (191 d; 21.2 kg). Our results show that at 84 feedlot days (approximately 204 d of life), sheep have a greater (14.5%) BW than goats, which may indicate a higher growth rate for sheep.

Studies have indicated differences in fat deposition in carcasses between sheep and goats ([Mahgoub and Lodge, 1998](#); [Santos et al., 2008](#)). Goats generally tend to deposit less subcutaneous fat, but more fat internally than sheep ([Shija et al., 2013](#); [Webb, 2014](#)). This agrees with our results, which show less fat deposition (%) and higher muscular deposition (%) in cold carcasses for goats than for sheep. Considering that the CP requirements of goats are greater than for sheep ([NRC, 2007](#)), goats are expected to start fat deposition later, which confirms the reason why goat carcasses may be leaner than those of sheep ([Sen et al., 2004](#); [Shija et al., 2013](#)). This fact is important because consumers concerns about the effect of fat on their health have led to lean meat being demanded more.

Figure 4. Nictmeral profile of the urea and creatinine ratio according to the evaluation time of sampling in spot urine with 2-h intervals on 2 consecutive days in goats (a) and sheep (b) after adjusting the following equation: $\hat{Y} = 3.71 + (-0.03 \times \text{SEN}(-0.2572 \times t))$; and $\hat{Y} = 10.67 + (0.15 \times \text{SEN}(-0.2389 \times t))$, with an estimated fundamental period of 12.2 and 13.1 h to repeat the estimated standard.

The fat:muscle ratio was lower in goats (average = 0.16) than in sheep (0.29). We also noted that feedlot days influenced protein deposition and fat in both sheep and goats. It has been recognized that when animals reach maturity, fat deposition increases and protein deposition reduces. Thus, we expected the fat:muscle ratio to rise in response to feedlot days. According to [Mahgoub and Lodge \(1998\)](#), the fat:muscle ratio is economically important because it is necessary to trim any excess carcass fat to lower the carcass value. Our results indicate that it is possible to reduce the slaughter BW for sheep compared to goats to avoid excess fat deposition in carcasses.

Despite sheep presenting greater N retention (approximately 61.8%) than goats, it is important to emphasize the significant increase in urinary excretion (39%) and fecal N (46.5%) in sheep. We also verified a similar relationship between N retained according to N apparently digested in both species,

which confirms that goats use N more efficiently for anabolic processes than sheep. Additionally, we verified a reduction in the relationship between N retained according to N ingested (19.85%) or N apparently digested (25.05%); however, it was observed similar N retention in response to feedlot days, indicating that the diet provided adequate amounts of absorbed protein that probably ensured similar muscle deposition.

Purine Derivatives, Creatinine, Urea, PD:C and U:C ratios

Our study results show that the PD excretions pattern differs between species. In sheep, the excretion of urinary allantoin, uric acid, xanthine and hypoxanthine increases, with approximately 58.15, 289.5, and 93.18%, respectively, compared with goats. This is not surprising because it has been well established that daily urinary PD excretions are

Figure 5. Observed means of the estimated urinary volume (liter/d) using the adjusted equation $\hat{Y} = 19.82 (\pm 1.49)X$ ($r^2 = 0.98$), according to sampling time with 2-h intervals for spot urinary collection; observed means of the estimated PD and urea excretions (mg/kg BW) at the same collection scheme; and its respective observed values obtained from 24-h total collection (control variable), with its respective comparison by Dunnet test (*means differed from control), evaluated in Dorper sheep and Boer goats.

correlated with DMI (Dórea et al., 2017), which were confirmed in the present study. However, the linear relationship between PD and DMI has a limitation because as DMI increases, passage rate increases as well. According to Dórea et al. (2017), greater passage rate increases microbial synthesis efficiency, but they also decrease the extent of OM digestion in the rumen, reducing substrate to microbial synthesis.

The model proposed by Chen and Gomez (1992), which used PD to estimate microbial protein

supply in sheep, is also used in most cases for goats. However, when considering that excretion PD is a function of the metabolic activity of xanthine-oxidase (Andrade-Montemayor et al., 2004), and that goat and sheep, respectively, presented a daily PD excretion of 0.54 and 0.83 mmol/kg BW^{0.75}, these results can be partly attributed to differences in the enzymatic activity of xanthine-oxidase between these species. It seems that a single model cannot be applied to both species as goats seem to have

greater xanthine-oxidase than sheep. Therefore, further studies are needed to develop specific models to predict microbial protein supply based on PD excretion for both goats and sheep.

Our results confirmed that daily creatinine excretion is a function of BW, CCW, and weight muscle, but is not influenced by DM or OM intake. We expected to find these facts because other authors have demonstrated that dietary factors do not influence creatinine excretion (Valadares et al., 1999; Chizzotti et al., 2008). However, creatinine excretion is frequently related to muscle tissue (Chizzotti et al., 2008; Costa e Silva et al., 2012). There was also a difference between species when creatinine excretion was considered a function of muscle weight. These results can be justified by differences in body composition as goats presented a lower percentage of lean tissue than sheep.

Despite the creatinine excretions obtained by spot urine samples not being affected by sampling time, the variability in the creatinine concentrations during sampling periods (diurnal and nocturnal) must be noted. In the present study, creatinine fluctuations demonstrated that the urine samples collected during diurnal period (0600 to 1800 h) contained a lower creatinine concentration than those collected during nocturnal (1800 to 0600 h) periods, but were much less prone to variations between feeding times. These differences can be attributed to the day–night diurnal variations in renal activity in both sheep and goats, which may reflect diuresis changing. The changes in final urine composition generally occur because of circadian glomerular filtration variations, reabsorption, and secretion processes in nephrons (Muszczyński et al., 2015). According to Skotnicka et al. (2007), the amount of excreted in urine in mammals is lower at night than when they are active during the day, which would justify higher urinary creatinine concentrations at night than in the daytime. This variability possibly indicates that the timing employed to take spot samples is critical, and that the diurnal period is more indicated for performing sampling.

Daily PD excretions presented differences throughout the time sampling, with greater excretions appearing during diurnal period for both species. Tao Ma et al. (2014) have reported that spot urine collections should be avoided in lambs immediately after feeding. These authors emphasize that allowing an appropriate lag phase between feeding time and sampling should be considered, and then sampling time should be done when the

PD concentration reaches a plateau in spot urine. Our results indicate that the ideal period to perform sampling in order to quantify the PD excretions is 3 h after the morning feed (1200 to 1600 h time sampling); which was also confirmed when PD excretion from spot samples were compared to those observed in total urine volume.

Lack of effect for the PD:C ratio obtained during spot sampling (2-h intervals) corroborates that reported by Chen et al. (1995) in a study with sheep. These authors report how the PD:C ratio undergoes insignificant daily fluctuations when animals are fed ad libitum, and the PD:C ratio correlates well with daily PD output. After considering the stability of the PD:C ratio during spot sampling, it confirmed that using urine spot samples performed at least 3 h after feeding, together with the PD:C ratio, can prove to be a satisfactory alternative to replace total urine collection and to estimate microbial synthesis in sheep and goats. Also, it must be highlighted that urinary volume estimated from spot samples taken at diurnal time points was closely related with the observed total urine collection, which may reinforce that recommendation.

Despite the U:C ratio obtained in spot samples with 2-h intervals obtaining higher values during diurnal periods than nocturnal periods, it is also important to consider the temporal variability of the U:C ratio obtained between animal species. The nictmeral profile of the U:C ratio has displayed a lower temporal variability measure over successive 24-h periods in goats than in sheep. These differences in U:C ratio patterns between species probably may be justified by variations in the interactions between ruminal degradation and nutrients supply to these species' intermediate metabolism. According to Spek et al. (2013), the need to retain N at low N intake levels results in changes in the renal regulation of urea excretion. As sheep present higher N intake than goats, greater CP rumen degradation and consequent increases in the magnitude in ruminal ammonia production would be expected, and also in the urinary excretion of N compounds after feeding. When considering that the behavior of variables was in accordance with the species' feeding patterns, it may be suggested that goats display a more continuous ingestive behavior in the daytime than sheep. Our results suggest that in order to estimate the urinary N excretions in goats and sheep, it is necessary to take the spot urine samples at least 3 and 2 schedules after feeding, respectively.

CONCLUSION

In similar maturity stages, sheep display greater growth rate than goats, which implies leaner goat carcasses than sheep, which appears more satisfactory for today's consumer demands. Our results also confirm that goats use N compounds for anabolic processes more efficiently than sheep, with lower urea N excretions. Thus, reducing the productive cycle could possibly avoid excess fat deposition and could also improve N utilization efficiency in sheep.

Purine derivative excretions correlated similarly with DM ($\hat{Y} = 0.009$ mmol/kg of DM) and OM (0.013 mmol/kg of OM) for both species. Based on our results, the allometric pattern can explain creatinine excretion based on muscle weight, were: $\hat{Y} = 89.04X^{0.9797}$ for goats and $\hat{Y} = 109.8X^{0.8002}$ for sheep.

The spot collection performed at least 3 h after feeding seems a satisfactory alternative to replace total urine collection and to estimate PD excretion in small ruminants. Our results suggest that in order to estimate N excretion in small ruminants, it is necessary to take 2 and 3 spot urine samples after feeding, respectively, for sheep and goats.

ACKNOWLEDGMENTS

Financial support for this research was provided by the National Council of Scientific and Technological Development (CNPq), the National Institute of Science and Technology in Animal Science (INCT – Ciência Animal), Coordination of Improvement of Personal Higher Education (CAPES), and the Foundation for Research Support of the State of Bahia (FAPESB).

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