Sjournals
Scientific Journals
Scientific Journal of Animal Science (2014) 3(11) 275-283
ISSN 2322-1704
doi, 10.14196/sjas.v3i11.1752

Contents lists available at Sjournals
Scientific Journal of Animal Science
Journal homepage: www.Sjournals.com

Original article

Serum and urine analyte comparison between llamas and alpacas fed three forages

T.F. Robinson*, B.L. Roeder
Brigham Young University, USA.

*Corresponding author; Brigham Young University, USA.

ARTICLE INFO

Article history,
Received 02 November 2014
Accepted 20 November 2014
Available online 29 November 2014

Keywords,
Alpacas
Llamas
Urine
Fractional excretion
Glomerular filtration rate

ABSTRACT

Serum and urine analytes were measured in 4 healthy adult llama and alpaca geldings housed in metabolism crates and fed three diets consisting of alfalfa (AH), barley (BH) or grass (GH) hay and water ad libitum. This comparative study was conducted to determine if differences exist in serum metabolites and urinary indices in llamas and alpacas consuming the same forages of differing protein and carbohydrate quality. Daily feed intake was determined and concurrent serum and urine samples were obtained at 4-hr intervals on d13 and d14 for analysis of electrolytes, urea N, and creatinine. AH was consumed more than BH or GH by both species, but llamas consumed more forage on both a body weight (BW) and metabolic BW (MBW, $kg^{.75}$) basis. Serum electrolytes were similarly affected by diet between species, indicating that renal homeostatic mechanisms were functional and analogous in llamas and alpacas. Serum and urine urea N were affected by forage ($P<0.05$). Urine volume was highest for both camelid species when consuming AH ($P<0.05$). Mean urine electrolyte excretion only differed by diet. Dissimilarities between these species was evidenced by differences in renal excretion of urea N and differences in urine volume on a MBW ($kg^{.75}$) basis.

1. Introduction

Little information is currently available concerning the metabolism and nutritional needs of pseudoruminant South American camelids. For this reason studies (Robinson et al. 2005, 2006, Davies et al. 2007a and 2007b) have been conducted in order to better understand their nutritional requirements and water metabolism (Rübsamen and Engelhardt, 1975). Llama and alpaca are distinguished by their ability to live at high altitude in climates too harsh for domestic ruminants to thrive. It has been suggested that alpacas (a close relative to the llama) are similar to llamas in respect to physiology and nutrient metabolism. In order to ascertain if nutrient metabolism differences exist between these two species, alpacas and llamas were studied while consuming three types of forages with differing protein and carbohydrate quality. The objectives of this study were to determine if serum and urine analytes, renal clearance, and fractional excretion of electrolyte and metabolite indices differed between alpacas and llamas fed either alfalfa, barley or grass hays.

2. Materials and methods

This experiment was conducted with the approval of the Brigham Young University Institutional Animal Care and Use Committee and followed humane animal care and husbandry practices. Clinically normal, adult gelding llamas (n = 4; 3 yrs old; 123±8 kg body weight (BW)) and gelding alpacas (n = 4; 3 yrs old; 60±4 kg BW) were used in this experiment. The animals were acclimated for 72 hrs to handling areas and metabolism crates (Davies et al. 2007a), and had ad libitum access to water and hay. The study animals were deemed to be clinically normal on the basis of history, physical examination findings, and results of CBC and serum biochemistry analysis. During the study, the camelids were housed in the metabolism crates (Davies et al. 2007a) but had twice daily 30 min exercise periods in a concrete-based paddock.

Three different forage treatments with differing protein quantity and carbohydrate quality, alfalfa (AH), barley (BH), or grass hay (GH), were fed in random order (Table 1). Animals were weighed with a digital scale immediately before and after each of the three treatment periods to calculate each camelid's average body weight during each treatment. Each treatment period lasted 14 days. Day 1 through 12 was used for feed acclimation, and d13 and d14 were used to collect timed urine and blood samples. Two days before each collection period, animals were fitted with a urine collection harness (Davies et al. 2007a) that consisted of a latex funnel attached to the caudoventral portion of the abdomen over the preputial area with a slight vacuum applied to draw urine into tubing attached to a plastic collection flask. Twenty-four hrs prior to initiation of this study, camelids were fitted with an indwelling jugular venous catheter (Micro-Renathane® .080"x .040", Braintree Scientific, Braintree, MA). Timed blood and urine samples were collected over twelve 4-hr intervals to determine each camelids renal clearance and fractional excretion measurements. During each collection period, 10ml of blood was obtained from each animal via intravenous catheter. Blood was allowed to clot, then centrifuged at 2000g for 20 min to separate serum from cellular fractions. Serum aliquots were frozen at -80˚C for future analysis. The urine volume excreted was measured every 4 hr, and samples were collected, aliquoted and frozen at -80˚C for future analysis.

Serum and urine samples were analyzed for Na, K, Cl, and urea N using a NOVA 16 analyzer (NOVA Biomedical, Waltham, MA). Serum and urine creatinine were determined by colorimetric method (#C513-480; TECO Diagnostics, Anaheim, CA).

Urine indices were calculated for each consecutive 4 hr interval consisting of periods 1-12 on d13-d14 for each of the three forage diets. Fractional excretion (FE) of Na, K, Cl, urea N, and creatinine was determined using the equation:

$$FEa = (Ua/Sa)/(UCr/SCr) \times 100,$$

where FEa is the fractional excretion of a substance expressed as a ratio or percentage of creatinine clearance, Ua and Sa are the urine and serum concentrations of analyte (a), and UCr and SCr are urine and serum concentrations of creatinine. Endogenous clearance (CLa) of Na, K, Cl, urea N, and creatinine was determined using the equation:

$$CLa = (Ua \times Uvol/Sa)/kg \text{ of BW and per kg metabolic body weight (MBW, kg.75)}$$

where CLa = endogenous clearance of a given analyte (a) or creatinine at a certain time, Ua and Sa = urine and serum concentrations of the analyte, respectively, or creatinine, Uvol = urine flow rate (ml/min) per kg BW and per kg MBW.

Total urinary excretion rate (TE) was calculated by the formula:

TEa = (Ua x Uvol)/kg of BW and per kg of MBW

where Ua and Sa are urine and serum concentrations of a particular analyte a, Uvol is urine flow rate in ml/min and also reported as output in ml/d, and UCr and SCr are urine and serum concentrations of creatinine. Glomerular filtration rate (GFR) was approximated via creatinine clearance, CLCr. The urinary filtered load (FL) and tubular absorption (TA) of analytes were calculated using the equations:

FL = (Sa*GFR)/kg of BW or per kg of MBW

TA = (FL-TE)/kg of BW or per kg of MBW

Statistical analysis of serum and urine analytes and the derived kidney function parameters were analyzed by the PROC GLM procedure of SAS (SAS, Inst., Cary, NC). The linear model included diet, animal species, and their interaction as fixed effects. In each of the three experiments, three periods were considered and animals were randomly fed one of the three experimental diets in a crossover design. Least square means for forage and species were determined using unadjusted t tests with a level of significance at $P<0.05$.

3. Results

The chemical composition of the three forages that comprised the experimental diets are shown in Table 1 expressed on a dry matter basis. Dry matter intake, g/kg.75/d, is shown in Table 2. Overall feed intake was significantly higher for llamas on a metabolic body weight basis than alpacas ($P<0.05$). Llamas consumed an average of 52.3 g/d/MBW of feed while alpacas consumed an average of 36.0 g/d/MBW. Alfalfa was the most consumed hay, regardless of species ($P<0.05$), with mean intake values for AH, BH, and GH of 48.9, 39.6, and 44.0 g/d/MBW, respectively.

Table 1
Chemical composition of feeds expressed on dry matter basis.

	Alfalfa	Barley	Grass
Crude protein, %	24.1	9.9	10.6
NDF, %	38.0	54.9	61.1
ADF, %	30.3	32.1	33.2
Calcium, %	1.7	0.4	0.5
Phosphorus, %	0.2	0.2	0.3
Potassium, %	3.7	1.3	2.1
Sodium, %	0.12	0.12	0.10
Chloride, %	1.4	0.67	1.3

Serum analyte concentrations (Table 2) were similar between llamas and alpacas with the exception of urea N which showed a difference between forages ($P<0.05$), where consumption of AH was related to higher concentrations in both species. No other differences were noted between species. Urine volume output, expressed on a MBW basis, showed a difference between forages ($P<0.05$; Table 3). When camelids consumed alfalfa hay, urine excretion rate was almost double that excreted during consumption of either the BH or GH treatments. Serum and urine analyte concentrations and timed urine volume output (Tables 2 and 3) were used to calculate the following urine indices: total excretion (TE; Table 4); clearance (CL; Table 5), fractional excretion (FE; Table 6), filtered load (FL; Table 7), and tubular absorption (TA; Table 8). Spearman's correlation coefficients for urine analyte FE, TE and CL for alpacas and llamas fed forages differing in quality is shown in Table 9. Expressed on a MBW basis, forage differences were noted for all analyte TE values except creatinine. Total excretion of sodium was affected by forage and highest for both species when consuming BH, followed by AH, and was lowest for GH ($P<0.05$). However, TE of Cl was affected by forage ($P<0.003$), species ($P<0.01$), and exhibited a forage by species interaction ($P<0.001$), with the highest values associated with consumption of AH in llamas. Potassium TE was affected by forage ($P<0.001$) and varied in similar fashion for llamas and alpacas ($P<0.05$) fed the same hay. However, TEK was similar to that found in either AH or BH when alpacas consumed GH. Urea N total excretion was affected by forage ($P<0.001$), species ($P<0.01$), and exhibited a forage by species interaction ($P<0.001$), with the highest values associated with consumption of AH and the most excreted by llamas. Differences existed on a MBW

basis between species (P<0.05) for total excretion of Cl, potassium and urea N, where AH was greater than the other diets.

Table 2
Dry matter intake and serum analyte concentrations of alpacas and llamas fed alfalfa, barley or grass hay.

	Alfalfa		Barley		Grass		
	Alpaca	Llama	Alpaca	Llama	Alpaca	Llama	SEM
Dry matter intake, g/d	856[a]	1996[c]	711[a]	1584[b]	699[a]	1899[c]	62.8
Dry matter intake, g/kg.75/d	40.8[b]	56.9[c]	33.8[a]	45.4b	33.5[a]	54.4[c]	2.1
Sodium, mmol/l	156.6	156.9	155.8	158.8	157.2	158.3	1.3
Chloride, mmol/l	123.0	122.0	122.2	123.8	123.9	123.6	1.1
Potassium, mmol/l	5.4	5.7	5.3	5.5	5.5	5.4	0.3
Urea N, mmol/l	7.9[b]	7.8[b]	4.4[a]	5.0[ab]	3.6a	4.0[a]	0.9
Creatinine, umol/l	145.9	145.9	160.0	163.0	126.4	159.5	16.8
Osmolality, mOsm/kg	310.6	313.0	310.1	316.9	312.2	315.2	3.2

abcMeans within rows with different superscripts differed at P<0.05.

Table 3
Urine volume and urine analytes in llamas and alpacas consuming alfalfa, barley or grass hay diets.

	Alfalfa		Barley		Grass		
	Alpaca	Llama	Alpaca	Llama	Alpaca	Llama	SEM
Urine volume							
ml/d	1310[a]	2845[b]	955[a]	1313[a]	559[a]	1331[a]	255
ml/min/kg	.015[b]	.017[b]	.012[ab]	.008[a]	.007[a]	.008[a]	.002
ml/d/MBW	50.2[d]	56.1[e]	32.4[c]	26.3[b]	19.0[a]	26.6[b]	0.91
Urine analytes, mmol/l							
Sodium	61.3[ab]	34.9[a]	83.5[bc]	109.7[c]	43.4[ab]	43.1[ab]	15.2
Chloride	417.9[a]	427.1[a]	484.4[ab]	696.9[b]	510.6[ab]	580.1[ab]	75.6
Potassium	195.4[ab]	157.4[a]	152.8[a]	146.1[a]	308.2[b]	189.2[ab]	48.4
Urea N	410.8[bc]	455.0[c]	316.7[abc]	317.6[abc]	274.3[a]	292.1[ab]	45.1
Creatinine, umol/l	15.4[ab]	10.8[a]	18.2b[c]	22.3[bc]	24.0[c]	21.3[bc]	2.5

[abcde]Means within rows with different superscripts differed at P<0.05.

Table 4
Total excretion (TE) of electrolytes and urea N in alpacas and llamas fed three forages of differing quality.

	Alfalfa		Barley		Grass		
	Alpaca	Llama	Alpaca	Llama	Alpaca	Llama	SEM
TE, µmol/min/kg							
Sodium	0.83[ab]	0.87[ab]	1.13[b]	1.03[b]	0.52[a]	0.47[a]	0.17
Chloride	6.89[ab]	8.76[b]	5.60[a]	6.61[ab]	5.80[ab]	6.38[ab]	0.60
Potassium	3.04[bc]	3.44[c]	2.30[ab]	1.40[a]	2.26[ab]	1.80[ab]	0.31
Urea N	7.62[b]	9.24[c]	3.23[a]	2.98[a]	3.17[a]	2.79[a]	0.42
Creatinine	252.9[ab]	223.3[ab]	215.5[a]	211.8[a]	287.6[b]	210.5[a]	21.54
TE, µmol/min/kg0.75							
Sodium	2.30[ab]	2.86[ab]	3.11[b]	3.35[b]	1.42[a]	1.53[a]	0.53
Chloride	19.0[ab]	28.8[c]	15.4[a]	21.5[b]	15.9[a]	20.6[ab]	1.85
Potassium	8.43[b]	11.21[b]	6.25[a]	4.57[a]	6.22[ab]	5.86[a]	0.96
Urea N	20.98[b]	30.28[c]	8.88[a]	9.72[a]	8.72[a]	9.11[a]	1.29
Creatinine	693.0[ab]	731.4[ab]	593.0[a]	690.0[ab]	791.0[b]	685.9[ab]	65.3

[abc]Means within rows with different superscripts differed at P<0.05.

Clearance rates (Table 5) for each electrolyte, expressed both on a per kg basis and on a MBW basis, showed differences (P<0.05) between forage, and had a species affect for the CLCl. Alpacas had similar CLCl values for each of the three forages consumed, whereas llamas had a higher CLCl when fed AH. The CLK was similar between these species when consuming the same forage treatment, but was higher for llamas when fed AH. Urea N clearance was affected by forage (P<0.001), but was similar between alpacas and llamas consuming the same diet treatment, with the highest urea N clearance associated with consumption of AH. Creatinine clearance was unaffected by forage and was similar between species on a MBW basis when animals consumed AH or BH, but was significantly higher in alpacas when fed GH.

Fractional excretion (Table 6) of Na, K, and urea N was affected by forage (P<0.05). The FENa for sodium was highest for both species when BH was consumed. The FECl was not different between forage treatments, but was affected by species, with llamas having the highest FE values when fed AH and BH followed by GH. The FE of urea N was highest in both alpacas and llamas fed AH (P<0.05) than the other two forages. However, for urea N there was a forage by species interaction (P<0.001). Potassium FE was not different between llamas and alpacas or between forages. The urinary FL for sodium and chloride (umol/min/kg) was significantly higher (P<0.05) for GH in alpacas only, while all other treatments had a similar FL of these electrolytes for both species. The FLK was highest when measured as ml/min/kg in alpacas consuming GH, but on a MBW basis, was not different between species or forages. The FL for urea N was affected by forage and exhibited a forage by species interaction (P<0.001), with the highest values associated with consumption of AH in llamas when measured on both a kg and MBW basis (P<0.05). There were also species differences in the TA of Na, Cl and K, on a umol/min/kg basis, being highest (P<0.05) for alpaca fed GH. However, when calculated on a MBW basis, the difference between alpacas and llamas was only significant for GH.

Correlations between FE, TE and CL (Table 9) indicated that these parameters correlated well for sodium for both species fed AH, but was less for BH. Alpacas fed GH did not correlate well, while llamas did. The other electrolyte FE to TE correlations were low. This was also true for urea N. The correlation between TE and CL were significant for all electrolytes, but less so for urea N.

4. Discussion

The alfalfa, barley, and grass forages in this study were selected to provide a wide range of nutritional quality defined as crude protein (CP), palatability and lignin content. In the case of AH, it had high quality (high CP, palatability and relatively low lignin), GH was intermediate and BH was a low quality forage. Dry matter intake (g/d) in this study was similar to that presented by Robinson et al. (2005 and 2006) and Davies et al. (2007a and 2007b) for alpacas and llamas fed alfalfa, barley and grass hays. In the aforementioned studies, DM intake between the species was significant, as was ours. When expressed on a MBW basis, intake differences between the two species remained significant. The DM intake differences for diet were expected and indicative of AH being the more palatable forage for both species.

Urine volume output was highest for the AH treatment by approximately 30 to 120% for alpacas and 112% for llamas with respect to the BH and GH treatments. Urine volume output is regulated by the kidneys in association with protein metabolism and the formation of nitrogenous wastes, primarily as urea nitrogen in mammals, along with the electrolytes Na and K, and mainly affected by the control of osmolality (Kume et al. 2008 and Bannink et al. 1999). Nitrogen intake calculated from DM intake and the forage CP values presented in Tables 1 and 2 were 1.6, 0.5 and 0.6 g/MBW/d for alpacas fed AH, BH and GH, respectively. A similar trend was noted for llamas; 2.2, 0.7 and 0.9 g/MBW/d for AH, BH and GH, respectively. The increased N intake for the AH treatment resulted in an increased urine output as the kidneys maintained osmolality homeostasis with increased levels of urea N removed by renal excretion.

The changes observed in serum urea N (SUN) concentration were in response to forage consumption, with AH causing an almost 300% increase in N intake above the BH and GH treatments. Our data correspond to results seen in other studies where alpacas were fed alfalfa and grass hays Robinson et al. (2005). Marini et al. (2004) demonstrated this same effect in growing dairy heifers. Total excretion of urine urea N (UUN) was highest for AH in conjunction with the higher N intake and corresponding elevation in SUN. Plasma urea N (PUN) has been shown to be a good predictor of UUN (Kume et al. 2008 and Kohn et al. 2005) and similarly, as PUN increased, UUN did as well. Kojima et al. (2005) demonstrated that K intake increased urine output and this effect resulted in an increased urinary N excretion. Hinderer and Engelhardt (1975) demonstrated that camelids recycle N at a higher

rate than other domestic ruminant species. They showed that llamas had a lower renal urea N excretion than sheep consuming the same diet and further concluded that urea N turnover in llamas is less than in sheep, 3% versus 12%, respectively. Farid et al. (1979) concluded that nitrogen conservation in camels is due to a decrease in fecal and urine N excretion. Though this may be true when dietary N intake is marginal or deficient, if it is in excess of requirement it will result in an increased SUN with its subsequent increased renal filtration and excretion (Kojima et al. 2005 and Albin et al. 1966).

Table 5
Renal clearance (CL) of electrolytes and urea N in alpacas and llamas fed three forages of differing quality.

	Alfalfa		Barley		Grass		
	Alpaca	Llama	Alpaca	Llama	Alpaca	Llama	SEM
Clearance, ml/min/kg							
Sodium	0.005^{ab}	0.006^{bc}	0.008^{c}	0.006^{bc}	0.004^{ab}	0.003^{a}	0.001
Chloride	0.056^{a}	0.072^{b}	0.044^{a}	0.053^{a}	0.048^{a}	0.052^{a}	0.005
Potassium	0.60b^{c}	0.64^{c}	0.43^{ab}	0.26^{a}	0.47b^{c}	0.35^{ab}	0.07
Urea N	1.34^{c}	1.22^{c}	0.79^{ab}	0.61^{a}	0.93^{b}	0.75^{ab}	0.08
Creatinine	1.62^{a}	1.74^{a}	1.58^{a}	1.37^{a}	2.36^{b}	1.36^{a}	0.19
Clearance, ml/min/kg0.75							
Sodium	0.015^{ab}	0.018^{ab}	0.021^{b}	0.021^{b}	0.010^{a}	0.010^{a}	0.003
Chloride	0.16^{a}	0.24^{b}	0.12^{a}	0.17^{a}	0.13^{a}	0.17^{a}	0.015
Potassium	1.65^{bc}	2.09^{c}	1.17^{ab}	0.84^{a}	1.29^{ab}	1.12^{ab}	0.20
Urea N	3.68^{b}	3.98^{b}	2.18^{a}	2.00^{a}	2.57^{a}	2.43^{a}	0.24
Creatinine	4.46^{a}	5.68^{ab}	4.23^{a}	4.45^{a}	6.25^{b}	4.42^{a}	0.57

^{abc}Means within rows with different superscripts differed at P<0.05.

Table 6
Urine fractional excretion (FE) of electrolytes and urea nitrogen in alpacas and llamas fed three forages of differing quality.

	Alfalfa		Barley		Grass		
	Alpaca	Llama	Alpaca	Llama	Alpaca	Llama	SEM
Fractional Excretion, %							
Sodium	0.38^{ab}	0.26^{ab}	0.39^{b}	0.53^{b}	0.16^{a}	0.33^{ab}	0.11
Chloride	3.5^{ab}	4.4^{c}	2.8^{ab}	4.2^{bc}	2.3^{a}	3.8^{b}	0.50
Potassium	38.3	35.8	25.3	18.4	36.0	26.9	9.2
Urea N	86.7^{c}	77.5^{c}	52.3^{b}	48.7^{ab}	42.1^{a}	57.6^{b}	3.4

^{abc}Means within rows with different superscripts differed at P<0.05.

Table 7
Filtered load (FL) of urine electrolytes and urea N in alpacas and llamas fed three forages of differing quality.

	Alfalfa		Barley		Grass		
	Alpaca	Llama	Alpaca	Llama	Alpaca	Llama	SEM
Filtered Load, ml/min/kg							
Sodium	0.25^{a}	0.27^{a}	0.24^{a}	0.22^{a}	0.37^{b}	0.21^{a}	0.03
Chloride	0.20^{a}	0.21^{a}	0.19^{a}	0.17^{a}	0.29^{b}	0.17^{a}	0.02
Potassium	0.008^{ab}	0.010^{bc}	0.008^{ab}	0.007^{a}	0.012^{c}	0.007^{a}	0.001
Urea N	0.009^{b}	0.013^{c}	0.007^{ab}	0.007^{ab}	0.008^{b}	0.005^{a}	0.001
Filtered Load, ml/min/kg0.75							
Sodium	0.69^{a}	0.89^{ab}	0.67^{a}	0.71^{a}	1.03^{b}	0.70^{a}	0.09
Chloride	0.54^{a}	0.69^{ab}	0.53^{a}	0.55^{a}	0.81^{b}	0.55^{a}	0.07
Potassium	0.023	0.032	0.023	0.024	0.034	0.023	0.003
Urea N	0.026^{b}	0.042^{b}	0.018^{a}	0.021^{a}	0.023^{a}	0.017^{a}	0.003

^{abc}Means within rows with different superscripts differed at P<0.05.

Table 8
Tubular absorption (TA) of urine electrolytes and urea N in alpacas and llamas fed three forages of differing quality.

	Alfalfa		Barley		Grass		
	Alpaca	**Llama**	**Alpaca**	**Llama**	**Alpaca**	**Llama**	**SEM**
TA, umol/min/kg							
Sodium	251.7[a]	271.1[a]	240.1[a]	217.1[a]	372.7[b]	214.0[a]	28.8
Chloride	191.5[a]	202.5[a]	184.9[a]	163.5[a]	288.7[b]	169.6[a]	23.1
Potassium	5.39[a]	6.37[a]	6.13[a]	6.09[a]	9.98[b]	5.34[a]	0.95
Urea N	1.73[a]	3.82[bc]	3.52[bc]	3.57[bc]	5.01[c]	2.37[ab]	0.74
TA, umol/min/kg0.75							
Sodium	691.4[a]	887.6[ab]	664.3a	706.4[ab]	1030.1[b]	695.8[a]	91.0
Chloride	525.9[a]	662.9[ab]	510.3a	531.9[a]	798.1[b]	546.7[a]	71.4
Potassium	14.7[a]	20.9[ab]	17.0a	19.8[ab]	27.6[b]	17.4[a]	2.9
Urea N	4.7[a]	12.6[b]	9.7ab	11.6[b]	13.9[b]	7.7[ab]	2.3

[abc]Means within rows with different superscripts differed at P<0.05.

Table 9
Spearman's correlation coefficients for urine analyte fractional excretion (FE), total excretions (TE) and clearance (CL) for alpacas and llamas fed forages differing in quality.

	Alfalfa		Barley		Grass	
	Alpaca	**Llama**	**Alpaca**	**Llama**	**Alpaca**	**Llama**
Sodium						
FE vs TE	.913	.802	.743	.751	.659	.927
FE vs TEma	.910	.816	.737	.752	.641	.927
TE vs CL	.998	.995	.999	.996	.997	.999
TEma vs CLma	.999	.999	.999	.997	.991	.999
Potassium						
FE vs TE	.578	.745	.723	.175	.638	.223
FE vs TEma	.610	.745	.698	.223	.638	.219
TE vs CL	.968	.986	.947	.930	.924	.934
TEma vs CLma	.964	.984	.929	.947	.929	.949
Chloride						
FE vs TE	-.043	-.116	.364	-.079	-.174	-.116
FE vs TEma	-.010	-.092	.361	-.080	-.285	
TE vs CL	.984	.976	.999	.997	.985	
TEma vs CLma	.990	.983	.999	.993	.982	-.092
Urea N						.976
FE vs TE	-.394	-.011	.454	.139	-.144	-.147
FE vs TEma	-.404	-.012	.432	.143	-.247	-.155
TE vs CL	.862	.932	.847	.799	.891	.823
TEma vs CLma	.875	.948	.842	.835	.894	.806

aExpressed on a metabolic weight basis

Urine analyte concentrations are presented for completeness, but their real importance is evidenced when used in calculating urinary total excretion (TE). Serum electrolytes were not affected by diet, nor were they different between species, indicating that renal homeostatic mechanisms were functional and analogous in llamas

and alpacas. Total analyte excretion expressed on a µmol/min/kg and µmol/min/MBW basis were all significant for forage except creatinine. Creatinine is associated with muscle metabolism via its utilization of creatine phosphate an energy source, and is produced at a steady rate by the degradation of creatine. Serum creatinine concentration has been shown to inversely reflect GFR, and creatinine clearance has previously been used in camelids to approximate GFR as the amount of creatinine filtered (Lackey et al. 1995). In our study, excretion of creatinine was significant for species when expressed on a per kg basis but not on a MBW basis. The reason for this difference was explained by Fleming et al. (1991), who indicated that herbivorous diets, devoid of exogenous creatinine, are not expected to influence creatinine clearance unless prolonged inadequate dietary intake results in a negative energy balance. Muscle mass, activity level and renal function can also affect creatinine clearance. The camelids in this study were relatively inactive and healthy, so the difference in creatinine excretion between species on a kg BW basis can be accounted for and is negated when expressed on a MBW basis.

Total electrolyte excretion rates were correlated with fractional excretion rate when studied in sheep (Garry et al. 1990). Fractional excretion was higher for Na and Cl in our animals than those reported for llamas by Lackey et al. (1995), while K was lower. Lefebvre et al. (2008) commented that there is normal intra-individual, as well as animal to animal and between species variation in FE that is due to the body requirement for the electrolyte and maintaining plasma levels within "normal" levels to maintain homeostasis. Clearance rate, as described by Swenson and Reece (1993), is a measure of the removal of a substance from the blood by the kidneys (such as a liter of blood cleared of analyte/d/MBW). The clearance of creatinine or CCR is often used as an estimate of GFR and was shown by Apple et al. (1989) to be very accurate (R2 = 0.92). Fleming et al. (1991) explained that CCR is variable between animals, but steady within an animal. This author concluded that because there was no time variation in their 6-hour collection period, CCR is a valid estimate of GRF in ruminants and herbivores. The mean CCR values calculated in our study were based on data collected over two days, providing a stable data set. We also used CCR to approximate GFR in camelids with the understanding that a small fraction of creatinine may also be secreted by the glomerulus. The GFR estimate for alpacas and llamas in our study is similar to that reported by others for camels and sheep (Fleming et al. 1991, Kamili et al. 2013 and Nawaz and Shah 1984).

5. Conclusion

These data demonstrate the effects of forage on serum and urine analytes and though there are some differences between the two camelid species, the major affect for differences in these analytes was from the effect of the forages. Species differences between alpacas and llamas may stem back to the greater DM intake of the forages by llamas and the associated increase in N consumption, particularly when high protein legumes like alfalfa hay are fed.

Acknowledgement

The authors wish to thank Micah Sharp, Christina Horey, Joseph Anderson and Adam Peterson for their assistance with animal care and laboratory analysis.

References

Albin, R.C., Clanton, D.C., 1966. Factors contributing to the variation in urinary creatinine and creatinine-nitrogen ratios in beef cattle. J Anim. Sci., 25, 107-112. http://www.journalofanimalscience.org/content/25/1/107.full.pdf+html?sid=33ebf61b-c9db-4091-b04b-4b61e979a44d

Apple, F.S., Benson, P., Abraham, P.A., Rosano, T.G., Halstenson, C.E., 1989. Assessment of renal function by inulin clearance: Comparison with creatinine clearance as determined by enzymatic methods. Clin. Chem., 35, 312-314. http://www.clinchem.org/content/35/2/312.full.pdf+html

Bannink, A., Valk A., Van Vuuren, A.M., 1999. Intake and excretion of sodium, potassium, and nitrogen and the effects on urine production by lactating dairy cows. J. Dairy. Sci., 82, 1008-1018. http://www.journalofdairyscience.org/article/S0022-0302(99)75321-X/pdf.

Davies, H.L., Robinson, T.F., Roeder, B.L., Sharp, M.E., Johnston N.P., Christensen, A.C., 2007a. Plasma metabolites and nitrogen balance in Lama glama and alpaca (Lama pacos) associated with forage quality at altitude. Small Rumin. Res. 69, 1-9. http://ac.els-cdn.com/S0921448805004906/1-s2.0-S0921448805004906-

main.pdf?_tid=bd5c87e4-5ebc-11e4-9fbe-00000aacb361&acdnat=1414512725_878a1a41e5efdd6fe212f571b9d80a2e.

Davies, H.L., Robinson, T.F., Roeder, B.L., Sharp, M.E., Johnston, N.P., Christensen, A.C., Schaalje, G.B., 2007b. Digestibility, nitrogen balance, and blood metabolites in llama (Lama glama) and alpaca (Lama pacos) fed barley or barley alfalfa diets. Small Rumin. Res. 73, 1-7. http://ac.els-cdn.com/S0921448806002859/1-s2.0-S0921448806002859-main.pdf?_tid=daa8100c-5ebc-11e4-aa47-00000aacb35d&acdnat=1414512774_d3dcafba405cd56e2b0762104503e73b.

Farid, M.F.A., Shawket, S.M., Abbel-Rahman, M.H.A., 1979. Observation on the nutrition of camels and sheep under stress. In: The Workshop of Camels, Khartoum, pp. 125–170.

Fleming, S.A., Hunt, E.L., Riviere, J.E., Anderson, K.L., 1991. Renal clearance and fractional excretion of electrolytes over four 6-hour periods in cattle. Am. J. Vet. Res., 52, 5-8.

Garry, F.B., Chew, D.J., Rings, D.M., Tarr, M.J., Hoffis, G.F., 1990. Renal excretion of creatinine, electrolytes, protein, and enzymes in healthy sheep, Am. J. Vet. Res., 51, 414-419.

Hinderer, S., Engelhardt, W.V., 1975. Urea metabolism in llama. Comp Biochem Physiol A. 52, 619-622. http://ac.els-cdn.com/S0300962975800120/1-s2.0-S0300962975800120-main.pdf?_tid=d23cb3e0-5ebd-11e4-a843-00000aab0f6b&acdnat=1414513189_076d815e644c52209add750830934889.

Kamili, A., Bengoumi, M., Oukessou, M., Faye, B., Lefebvre, H.P., 2013. Assessment of glomerular filtration rate in normally hydrated and dehydrated dromedary camel by plasma exogenous creatinine clearance test. Em. J. Food Agric., 25, 314-319. http://ejfa.info/index.php/ejfa/article/view/15501/8281.

Kohn, R.A., Dinneen, M.M., Russek-Cohen, E., 2005. Using blood urea nitrogen to predict nitrogen excretion and efficiency of nitrogen utilization in cattle, sheep, goats, horses, pigs, and rats. J Anim. Sci., 83, 879-889. http://www.journalofanimalscience.org/content/83/4/879.

Kojima, H., Kume, S., Nonaka, K., Oshita, T., Kozakai, T., Hirooka, H., 2005. Effects of feeding and animal performance on nitrogen, phosphorus and potassium excretion by Holstein cows. Anim. Sci. J., 76, 139-145. http://onlinelibrary.wiley.com/doi/10.1111/j.1740-0929.2005.00249.x/pdf.

Kume, S., Nonaka, K., Oshita, T., Kozakai, T., Hirook, H., 2008. Effects of urinary excretion of nitrogen, potassium and sodium on urine volume in dairy cows. Livestock Sci. 115, 28-33. http://ac.els-cdn.com/S1871141307003812/1-s2.0-S1871141307003812-main.pdf?_tid=9a79f1ae-5ec0-11e4-8e06-00000aacb362&acdnat=1414514384_3aff3ae45d00a65d7c5342696b0c6b5a.

Lackey, M.N., Belknap, E.B., Salman, M.D., Tinguely, L., Johnson, L.W., 1995. Urinary indices in llamas fed different diets. Am. J. Vet. Res., 56, 859-865.

Lefebvre, H.P., Dossin, O., Trumel, C., Braun, J.-P., 2008. Fractional excretion tests: a critical review of methods and applications in domestic animals. Vet. Clin. Path., 37, 4-20. http://onlinelibrary.wiley.com/doi/10.1111/j.1939-165X.2008.00010.x/pdf.

Marini, J.C., Klein, J. D., Sands, J. M., Van Amburgh, M.E., 2004. Effect of nitrogen intake on nitrogen recycling and urea transporter abundance in lambs. J. Anim. Sci., 82, 1157-1164. http://www.journalofanimalscience.org/content/82/4/1157.full.pdf+html.

Nawaz, M., Shah, B.H., 1984. Renal clearance of endogenous creatinine and urea in sheep during summer and winter. Res.Vet. Sci., 36, 220-224.

Robinson, T.F., Hammer, J.D., Roeder, B.L., Burton, S., Christensen, M., Schaajle, B., 2005. Nitrogen balance and blood metabolites of alpaca (Lama pacos) fed three forages of different protein content. Small Rumin. Res. 58, 123-133. http://ac.els-cdn.com/S0921448804002391/ 1-s2.0-S0921448804002391-main.pdf?_tid=15948394-5ebd-11e4-b8ec-00000aacb361&acdnat=1414512873_9124b6f3ab76331acfc718dc1d167079

Robinson, T.F., Sponheimer, M., Roeder, B.L., Passey, B., Cerling, T.E., Dearing, M.D., Ehleringer, J.R., 2006. Digestibility and nitrogen retention in llamas and goats fed C3 grass, and C4 grass hays. Small Rumin. Res. 64, 162-168. http://ac.els-cdn.com/S0921448805001653/1-s2.0-S0921448805001653-main.pdf?_tid=36b13d42-5ebd-11e4-a012-00000aacb361&acdnat=1414512928_a0739938cd898cb006f90c5448757642.

Rübsamen, K., Engelhardt, W.V., 1975. Water metabolism in the llama. Comp Biochem Physiol A. 52, 595–598. http://ac.els-cdn.com/S0300962975800065/1-s2.0-S0300962975800065-main.pdf?_tid=a520f33a-5ebd-11e4-a73b-00000aacb360&acdnat=1414513114_902feef6caa413b5f49165c6e82d26f3.

Swenson, M.J., Reece, W.O., 1993. Water balance and excretion. in Dukes' Physiology of Domestic Animals. 11th ed. Cornell Univ. Press, Ithaca, NY, pp. 573–604.