Published December 3, 2014

Evaluation of four raw meat diets using domestic cats, captive exotic felids, and cecectomized roosters

K. R. Kerr,* A. N. Beloshapka,† C. L. Morris,‡ C.M. Parsons,† S. L. Burke,‡ P. L. Utterback,† and K. S. Swanson*†[1]

*Division of Nutritional Sciences and †Department of Animal Sciences, University of Illinois, Urbana 61801; and ‡Omaha's Henry Doorly Zoo and Aquarium, Omaha, NE 68107

ABSTRACT: Our objective was to evaluate raw meat diets for captive exotic and domestic carnivores containing traditional and alternative raw meat sources, specifically, beef trimmings, bison trimmings, elk muscle meat, and horse trimmings. We aimed to examine diet composition and protein quality; apparent total tract energy and macronutrient digestibility in domestic cats, African wildcats, jaguars, and Malayan tigers; and ME and fecal fermentative end-products in domestic cats. Because of variation in the meat sources, dietary proximate, AA, and long-chain fatty acid composition were variable. Our analyses indicated that all diets had essential fatty acid deficiencies, and the elk diet (i.e., trimmed muscle meat) was deficient in total fat. Standardized AA digestibilities measured using the cecectomized rooster assay were high (>87%). Using the NRC minimum requirements for the growth of kittens, the first limiting AA of all diets was the combined requirement of Met and Cys (AA score: 81 to 95; protein digestibility corrected AA score: 75 to 90). All diets were highly digestible (88 to 89% OM digestibility). There was no effect of diet or felid species on DM (85 to 87%), OM, and GE (90 to 91%) digestibilities. Apparent CP digestibility was greater ($P \leq 0.05$) in cats fed elk (97%) compared with those fed bison (96%), and greater ($P \leq 0.05$) in wildcats (97%) and domestic cats (97%) compared with tigers (95%). The diet and species interaction ($P \leq 0.05$) was observed for apparent fat digestibility. In domestic cats, the fresh fecal pH and proportions of acetate and butyrate were altered ($P \leq 0.05$) due to diet. Diet also affected ($P \leq 0.05$) fresh fecal concentrations of total branched-chain fatty acids, valerate, and *Lactobacillus* genus. In conclusion, although the raw meat diets were highly digestible, because of variation in raw meat sources the nutrient composition of the diets was variable. Thus, compositional analysis of raw meat sources is necessary for proper diet formulation. The types of meat commonly used in raw meat diets may be deficient in total fat (trimmed muscle meat) and essential fatty acids (trimmings and muscle meats). Additionally, differences in raw meat source nutrient composition and digestibility affect the beneficial and putrefactive fermentative end-products found in feces.

Key words: blood metabolites, comparative nutrition, digestibility, fermentative end-products, microbiota

J. Anim. Sci. 2013.91:225–237
doi:10.2527/jas2011-4835

INTRODUCTION

Captive exotic felids in the United States are traditionally fed horsemeat-based raw diets. Although several studies have evaluated raw meat diets in captive exotic felids (Clauss et al., 2010; Vester et al., 2010a,b), most have focused on horsemeat and beef-based diets. With the closing of horse abattoirs in 2007, the availability of quality grade horsemeat in the United States has decreased, increasing the need for research on the digestibility and composition of possible alternatives.

Domestic cats are the primary model for nutritional and metabolic information for captive exotic species; however, the authors are aware of only 1 peer-reviewed article that directly compared the domestic cat with captive exotic felids (Vester et al., 2010a).

[1]Corresponding author: ksswanso@illinois.edu
Received October 18, 2011.
Accepted September 4, 2012.

Additionally, the feeding of unconventional diets, including those based on raw meat, has increased in show animals and pets. Further evaluation of raw meat diets in the domestic cat, and validation of models for domestic and captive exotic feline species are necessary.

The objective of this study was to evaluate 4 raw meat-based diets, specifically beef, bison, elk, and horse. We aimed to examine diet composition and protein quality; apparent total tract energy and macronutrient digestibility in domestic cats, African wildcats, jaguars, and Malayan tigers; and ME, fecal fermentative end-products, and blood metabolites in domestic cats.

We hypothesized that diet composition would be variable due to variation in the animal-based protein sources (i.e., ruminant vs. nonruminant and muscle meat vs. trimmings); however, all diets would meet the AA and fatty acid requirements of the domestic cat. We also hypothesized that the protein in muscle meat of elk would be more digestible than the connective tissues present in trimmings of the other diets. In addition, we hypothesized that variable diet composition would result in alterations of fecal fermentative end products.

MATERIALS AND METHODS

All animal procedures were approved by the Omaha's Henry Doorly Zoo and Aquarium (**OHDZA**) and University of Illinois Institutional Animal Care and Use Committees before animal experimentation.

Diet Composition

Four raw meat-based dietary treatments were studied (Table 1). Based on estimated composition, all diets were formulated to meet or exceed the nutrient requirements of domestic cats (NRC, 2006). Ingredient composition for all diets was similar to diets currently fed at the OHDZA and included a raw meat source (98.6%; beef: beef trimmings; bison: bison trimmings; elk: muscle meat; and horse: horse trimmings), cellulose (1.9%; Solka Floc, International Fiber, North Towanda, NY), and feline vitamin and mineral premix (1.3%; Meat Complete; Central Nebraska Packing, Inc., North Platte, NE). The 3 meat trimmings are readily available commercially for use in feline diets, whereas the elk muscle meat was a source that was available and of interest to the researchers. Each dietary treatment was subsampled, composited, and lyophilized (Dura-Dry MP Microprocessor-Controlled Freeze-Dryer; FTS Systems, Stone Ridge, NY), then ground with dry ice through a 2-mm screen (Wiley Mill Model 4; Thomas Scientific, Swedesboro, NJ). Treatments were determined for DM, OM, CP, and N (AOAC, 2006), acid hydrolyzed fat (Budde, 1952; AACC, 1983), total dietary fiber (TDF;

Table 1. Chemical and ingredient composition of beef-, bison-, elk-, and horsemeat-based raw diets fed to domestic and captive exotic felids (DM basis)[1]

Item	Beef	Bison	Elk	Horse
DM, %	29.0	34.1	28.8	34.1
OM, %	93.1	95.3	93.2	94.6
CP, %	64.5	52.2	76.6	59.0
Acid hydrolyzed fat, %	22.2	36.6	6.5	25.1
Total dietary fiber, %	8.4	6.6	12.0	7.2
GE, kcal/g	5.9	6.6	5.3	6.0
Calculated ME,[2] kcal/g	4.7	5.7	4.0	5.1
Estimated ME,[3] kcal/g	4.6	5.4	3.6	4.8
AA, %	62.68	49.73	73.99	56.70
TIAA[4]	30.60	23.46	38.55	28.34
Arg	4.15	3.43	4.84	3.80
His	2.12	1.40	2.98	2.18
Ile	2.93	2.09	3.67	2.73
Leu	5.08	3.91	6.44	4.68
Lys	5.45	4.06	6.95	4.89
Met	1.58	1.15	2.07	1.42
Phe	2.56	2.04	3.22	2.36
Taurine	0.21	0.46	0.37	0.24
Thr	2.57	1.92	3.20	2.34
Trp	0.70	0.49	0.80	0.67
Val	3.28	2.52	4.03	3.03
TDAA[5]	32.08	26.26	35.44	28.37
Ala	4.08	3.33	4.52	3.60
Asp	5.61	4.31	6.92	5.16
Cys	0.65	0.49	0.77	0.57
Glu	9.15	6.78	10.93	8.14
Gly	4.17	4.12	3.55	3.61
Hydroxy Lys	0.14	0.12	0.06	0.07
Hydroxy Pro	0.86	1.12	0.19	0.56
Lanthionine	0.00	0.00	0.00	0.00
Ornithine	0.08	0.06	0.14	0.07
Pro	2.95	2.75	2.89	2.66
Ser	2.07	1.55	2.28	1.75
Tyr	2.34	1.64	3.21	2.19
Total fatty acids, mg/g	173.64	289.63	61.90	185.91
Linoleic acid	3.24	5.73	2.71	4.39
α-linolenic acid	0.61	1.25	0.11	0.73
Arachidonic acid	0.64	0.81	0.81	0.12
Eicosopentaenoic acid	0.15	0.16	0.02	ND[7]
Docosahexaenoic acid	0.03	0.08	0.02	ND
Total SFA	78.45	130.21	27.37	77.95
Total BCFA[6]	4.71	7.94	1.51	3.13
Total MUFA	77.20	126.52	18.45	66.93
Total n-3 PUFA	0.88	1.62	0.23	0.73
Total n-6 PUFA	4.48	7.06	5.69	5.01
Total PUFA	5.36	8.68	5.92	5.75
CLA	1.59	1.63	0.13	2.61
n-6:n-3	5.06	4.62	24.45	8.32

[1]Ingredient composition for all diets: raw meat source (98.6%; beef: beef trimmings; bison: bison trimmings; elk: muscle meat; and horse: horse trimmings), cellulose (1.9%; Solka Floc; International Fiber, North Towanda, NY), and feline vitamin and mineral premix (1.3%; Meat Complete; Central Nebraska Packing, Inc., North Platte, NE).

[2]Calculated ME = GE intake (kcal/d) – fecal GE (kcal/d) – urinary GE (kcal/d)/DMI (g/d); determined for domestic cats only.

[3]Estimated ME = 9 kcal/g fat + 4 kcal/g CP + 4 kcal/g nitrogen free extract (NRC, 2006).

[4]TIAA = total indispensableAA.

[5]TDAA = total dispensable AA.

[6]BCFA = branch chain fatty acids.

[7]ND = not detected.

Prosky et al., 1994), AA (AOAC, 2006; University of Missouri Experiment Station Chemical Laboratories, Columbia, MO), and long-chain fatty acid (Lepage and Roy, 1986) concentrations, and GE by a bomb calorimeter (Model 1261; Parr Instrument Co., Moline, IL).

Cecectomized Rooster Assay and Protein Quality

A cecectomized rooster assay was performed to evaluate standardized AA digestibility of the 4 ground, lyophilized dietary treatments. Briefly, 16 cecectomized roosters that had been fasted for 26 h to empty the digestive tract of all dietary residues were crop-intubated with approximately 20 to 30 g of 1 of the 4 dietary treatments (4 roosters/diet). All excreta were collected over a 48-h period, then lyophilized and analyzed for AA according to the methods described for diet composition. Endogenous excretion of AA was measured using roosters that were fasted for 48 h. The latter values were used to calculate standardized AA digestibility values, using the method described by Sibbald (1979). Data were analyzed using the Mixed Models procedure (SAS Inst. Inc., Cary, NC). The fixed effect of diet was tested. Differences among diets were determined using a Fisher-protected LSD with a Tukey adjustment to control for experiment-wise error. A probability of $P \leq 0.05$ was accepted as statistically significant. Reported pooled SEM were determined according to the Mixed Models procedure of SAS. Standardized digestibility was used to determine the protein digestibility corrected AA (PDCAAS) using the equation: PDCAAS = mg of AA in 1 g of test protein/mg of AA in 1 g of reference protein × standardized AA digestibility (%) × 100 (FAO/WHO/ÚNU Expert Consultation, 2007). To determine the impact of digestibility on scores, the AA score (AAS) was also calculated. We used the equation: AAS = mg of limiting AA in 1 g of test protein/mg of limiting AA in 1 g of reference protein × 100. The reference pattern used was the minimal requirements for growth of kittens provided by NRC (2006) for domestic cats. Scores were determined by selecting the AA with the lowest value, i.e., the first limiting AA (**LAA**).

Total Tract Energy and Macronutrient Digestibility

Eight intact adult female domestic cats (*Felis catus*; mean age = 2.01 ± 0.03 yr; mean BW = 3.25 ± 0.31 kg) and 4 animals of each captive exotic species (African wildcat (*Felis silvestris tristrami*), jaguar (*Panthera onca*), and Malayan tiger (*Panthera tigris corbetti*)) were used. Captive exotic animal data are presented in Table 2. The amount of food offered was calculated using preliminary dietary compositional data and historic caloric intakes. Domestic cats were fed to maintain BW (measured twice weekly) and captive exotic species were fed to maintain BCS. Body condition score was determined by the nutritionist using a 5-point scale (1 = emaciated, 3 = ideal, and 5 = obese).

Table 2. Sex, BW, BCS, and age of captive exotic felids[1,2]

Species	Sex	BW, kg	BCS	Age, yr
African wildcat	Female	3.1	3.0	4.0
	Female	3.3	3.0	4.0
	Male	4.6	3.0	2.9
	Male	3.7	3.0	2.9
Jaguar	Female	50	3.0	6.9
	Male	51	3.0	6.0
	Male	57	3.5	1.9
	Male	59	3.0	19.0
Malayan tiger	Female	103	3.0	3.3
	Female	88	3.0	13.4
	Female	96	2.5	13.4
	Male	97	3.0	8.0

[1]BW = determined at most recent medical examination.

[2]BCS = determined on a 5-point scale with 1 = emaciated, 3 = ideal, and 5 = obese. All BCS were determined with special consideration of the species being evaluated.

Domestic cats were housed individually in stainless steel cages (0.61 × 0.61 × 0.61 m) at the University of Illinois in a temperature- (21°C) and light-controlled (14 h light:10 h dark) room. Exotic felids were housed individually in indoor and outdoor concrete floor enclosures maintained by the OHDZA (Omaha, NE). Exotic felids were allowed access to outdoor enclosures during the entire study (May to August). Water was provided ad libitum.

A crossover design was used with animals being randomized individually to 1 of the 4 dietary treatments. Animals were adapted to dietary treatments for 16 d before a 5-d collection period. During the collection period, food intake and fecal output were measured daily for all species. Domestic cats were fed twice daily (at 0800 and 2000 h), whereas captive exotic felids were feed once daily (before 1200 h). To account for potential evaporative losses of meat, food intake was determined using the equation: food offered (g as-is × dietary DM content) − food refusals (g DM). Animal cages/enclosures were checked for total fecal samples twice daily. Fecal samples were scored daily. Scoring was conducted using a 5 point scale as follows: 1 = hard, dry pellets; 2 = dry, well-formed stools; 3 = soft, moist, formed stool; 4 = soft, unformed stool; and 5 = watery, liquid that can be poured. For each animal, total fecal output was collected for each period, composited, dried at 55°C, and ground through a 2-mm screen (Wiley Mill intermediate, Thomas Scientific, Swedesboro,NJ). Composited fecal samples were analyzed for DM, OM, CP, GE, and fat

concentrations as described for diet composition determination. Apparent total tract digestibility values were calculated using this equation: [nutrient intake (g/d) − fecal output (g/d)]/nutrient intake (g/d) × 100.

Digestibility data were analyzed using the Mixed Models procedure of SAS. The fixed effects of species and diet were tested and the interaction term investigated. Period and animal were considered random effects. Differences were determined using a Fisher-protected LSD with a Tukey adjustment to control for experimentwise error. A probability of $P \leq 0.05$ was accepted as statistically significant. Reported SEM were determined according to the Mixed Models procedure of SAS.

Metabolizable Energy, Fresh Fecal Characteristics, Blood Metabolites

During the collection period for domestic cats, total urine, fresh fecal, and serum samples were also collected. These data were used to measure ME, fresh fecal characteristics, and blood metabolites of domestic cats only. To ensure complete collection and prevent urine N loss, urine was collected and stored according to Kerr et al. (2012). Total urine samples were analyzed for GE concentrations as described for diet composition. Metabolizable energy from domestic cats only was calculated using the equation: ME_C = GE intake (kcal/d) – fecal GE (kcal/d) – urinary GE (kcal/d)/DM intake (g/d). To allow for comparison of methods, dietary ME was also estimated using dietary composition and the equation: ME_E = 9 kcal/g fat + 4 kcal/g CP + 4 kcal/g nitrogen free extract (NRC, 2006).

Fresh fecal samples were obtained within 15 min of defecation. Immediately after collection, fresh fecal weight, pH (APIO pH Meter, Denver Instrument, Bohemia, NY; and Beckman Electrode, Beckman Instruments, Inc., Fullerton, CA) and fecal scores were determined. Fecal pH was determined by inserting the probe into the interior of the fresh fecal sample. Fresh fecal samples were analyzed for ammonia (Chaney and Marbach, 1962), short-chain fatty acid (**SCFA**; acetate, butyrate, and propionate) and branched-chain fatty acid (**BCFA**; valerate, isovalerate, and isobutyrate; Erwin et al., 1961), and phenol and indole (Flickinger et al., 2003) concentrations. Fresh fecal *Escherichia coli*, *Bifidobacterium* genus, *Lactobacillus* genus, and *Clostridium perfringens* were quantified via quantitative PCR (qPCR) using specific primers according to Middelbos et al. (2007) and Lubbs et al. (2009).

Serum samples were collected on the final day of each period. Four milliliters of blood were collected from food-restricted (>12 h) domestic cats under physical restraint by femoral or jugular venipuncture. Samples were immediately transferred to tubes (BD, Franklin Lakes, NJ). All tubes were centrifuged at 1,100 to 1,300 × *g* for 15 min at 4°C. The supernatant was collected and stored at −80°C. Serum metabolite concentrations were determined (Hitachi 911 Clinical Chemistry Analyzer; Roche Diagnostics, Indianapolis, IN) by the University of Illinois Veterinary Diagnostic Laboratory.

RESULTS

Dietary Composition

Dietary DM concentrations were similar in bison and horse diets (34%), and similar in beef and elk diets (29%; Table 1). Organic matter concentrations were similar among diets (93 to 95%). Crude protein, total AA (**TAA**), total indispensable AA (**TIAA**), and total dispensable AA (**TDAA**) concentrations were lowest in bison and greatest in elk, with other protein sources being intermediate. Acid-hydrolyzed fat, total fatty acid (**TFA**), SFA, BCFA, and MUFA concentrations, and GE values were least in elk and greatest in bison (Table 1). Poly-unsaturated fatty acids were least in horse and greatest in the bison. Linoleic acid (**LA**), and α-linolenic acid (**ALA**) were least in elk and greatest in bison. Arachidonic acid (**ARA**) was least in horse and greatest in bison and elk. Eicosopentaenoic acid (**EPA**) and docosahexaenoic acid (**DHA**) were least in horse and greatest in bison. Total omega-3 PUFA were least in elk and greatest in the bison, whereas omega-6 PUFA were least in beef and greatest in bison. The ratio of omega-6 to omega-3 PUFA was least in beef and greatest in elk. All diets had a similar proportion of SFA (42 to 45% of TFA). The elk diet had greater proportion of PUFA (10 vs. 3% of TFA) compared with all other diets and reduced proportion of MUFA (30 vs. 43 to 44% of TFA) compared with beef and bison, whereas horse was intermediate (36% of TFA).

Rooster Assay

Standardized AA digestibility coefficients are presented in Table 3. There were few differences due to diet for individual AA. Average digestibility of all individual AA except His (87 ± 4%), and Cys (88 ± 4%) were greater than 90%. Digestibility of TIAA (93 ± 2%), TDAA (90 ± 3%), and TAA (91 ± 2%) were not different among treatments. When evaluating AA score(**AAS**) and protein digestibility-corrected AA score (**PDCAAS**), the first LAA for all diets was the combined requirement for methionine and cysteine. Amino acid score values were 4 to 7 points greater than PDCAAS values (Table 4).

Table 3. Standardized digestibility (%) of AA of beef-, bison-, elk-, and horsemeat-based raw diets determined using the precision-fed cecectomized rooster assay[1]

	Diet					
AA	Beef	Bison	Elk	Horse	SEM	*P*-value
Indispensable						
Arg	94.3	94.3	91.1	92.7	1.8	0.55
His	89.8	88.6	84.3	84.7	1.4	0.06
Ile	96.5	95.9	96.5	94.7	0.5	0.07
Leu	96.9	96.5	97.0	95.5	0.5	0.13
Lys	91.4	91.8	90.7	88.2	2.5	0.74
Met	97.5	96.8	97.2	96.1	0.4	0.13
Phe	95.7[a,b]	95.3[a,b]	96.0[b]	93.5[a]	0.6	0.04
Thr	95.3	95.0	95.3	93.4	0.8	0.34
Trp	98.3[a,b]	99.5[b,c]	97.1[a]	98.8[b,c]	0.4	0.01
Val	95.5	94.7	96.1	93.8	0.7	0.19
Dispensable						
Ala	96.0	95.5	96.3	94.4	0.6	0.14
Asp	95.8	95.2	95.7	94.1	0.6	0.19
Cys	90.8	87.1	88.6	84.6	2.0	0.23
Glu	95.5	95.4	95.0	94.5	0.5	0.55
Pro	94.0	93.5	93.1	90.8	1.1	0.21
Ser	94.8	93.6	94.8	92.3	1.1	0.36
Tyr	94.5[b]	94.3[a,b]	92.1[a,b]	91.2[a]	0.8	0.03
TIAA[2]	94.1	93.2	92.8	91.7	0.9	0.39
TDAA[3]	91.9	90.3	88.1	87.6	1.4	0.16
TAA[4]	93.0	91.7	90.6	89.7	1.1	0.24

[a-c]Mean within a row lacking a common superscript letter differ ($P \leq 0.05$).

[1]Data are means of 4 roosters.

[2]TIAA = total indispensable AA.

[3]TDAA = total dispensable AA.

[4]TAA = total AA.

Total Tract Macronutrient and Energy Digestibility

For cats fed beef, bison, and elk, intake (g DM/d/kg $BW^{0.75}$) was greater ($P \leq 0.05$) in tigers as compared with domestics and wildcats (Table 5). For cats fed horse, intake (g DM/d/kg $BW^{0.75}$) was greater ($P \leq 0.05$) in tigers as compared with domestics and wildcats, and greater ($P \leq 0.05$) in jaguars as compared with domestics. For jaguars and tigers, intake (g DM/d/kg $BW^{0.75}$) was greater ($P \leq 0.05$) in cats fed bison as compared with those fed elk. For domestics, intake (g DM/d/kg $BW^{0.75}$) was greater ($P \leq 0.05$) in cats fed bison and elk as compared with those fed horse. There was no effect of diet on intake for wildcats. For cats fed beef, elk, and horse, fecal output (g DM/d/kg $BW^{0.75}$) was greater ($P \leq 0.05$) in tigers as compared with domestics and wildcats. For cats fed bison, fecal output (g DM/d/kg $BW^{0.75}$) was greater ($P \leq 0.05$) in tigers as compared with domestics and wildcats, and greater ($P \leq 0.05$) in jaguars as compared with domestics. For domestics, fecal output (g DM/d/kg $BW^{0.75}$) was greater ($P \leq 0.05$) in cats fed elk as compared with those fed horse. There was no effect of diet on fecal output for wildcats, jaguars, or tigers. Fecal DM was greater ($P \leq 0.05$) in domestic cats (59%) and wildcats (55%) as compared with jaguars (43%) and tigers (38%), and greater ($P \leq 0.05$) in jaguars as compared with tigers. For domestic cats, fecal score was greater ($P \leq 0.05$) in cats fed beef as compared with those fed horse. For bison, fecal score was greater ($P \leq 0.05$) in tigers as compared with domestic cats. For the elk diet, fecal score was greater ($P \leq 0.05$) in tigers as compared with wildcats and domestic cats. For the horse diet, fecal score was greater ($P \leq 0.05$) in wildcats, jaguars, and tigers as compared with domestic cats.

There was no effect of diet or species on total tract DM, OM, and GE digestibilities. Apparent total tract CP digestibility was greater ($P \leq 0.05$) in wildcats and domestic cats as compared with tigers. Apparent total tract CP digestibility was greater ($P \leq 0.05$) for cats fed elk as compared with those fed bison and horse, and greater ($P \leq 0.05$) in those fed beef as compared with those fed bison. For cats fed bison, apparent total tract fat digestibility was greater ($P \leq 0.05$) in domestics as compared with jaguars and tigers, and greater ($P \leq 0.05$) in wildcats as compared with jaguars. There was no effect of species for any other diet type. For domestics, apparent total tract fat digestibility was greater ($P \leq 0.05$) in cats fed beef, bison, and horse as compared with those fed elk. For jaguars, apparent total tract fat digestibility was greater ($P \leq 0.05$) in cats fed horse as compared with those fed bison and elk.

Table 4. Amino acid score (AAS), protein digestibility-corrected AA score (PDCAAS), and first limiting AA (LAA) of beef-, bison-, elk-, and horsemeat-based raw diets fed to domestic and captive exotic felids using domestic cat life stage minimal requirements for growth of kittens as reference values[1]

Diet	AAS	PDCAAS	LAA
Beef	89	85	Met + Cys
Bison	81	75	Met + Cys
Elk	95	90	Met + Cys
Horse	87	80	Met + Cys

[1]NRC (2006).

Metabolizable Energy

Metabolizable energy ($\mathbf{ME_C}$) was calculated using data only from domestic cats, and estimation of $\mathbf{ME_E}$ was done by using dietary composition. Metabolizable energy (ME_C and ME_E) were least in elk (4.0 and 3.6 kcal ME/g DM, respectively) and greatest in bison (5.7 and 5.4 kcal ME/g DM; Table 1). For beef, ME_C and ME_E were similar (0.1 kcal/d DM difference). For bison, elk, and horse, however, the ME_E was 0.3 to 0.4 kcal/g DM less than the ME_C.

Table 5. Intake, fecal output, fecal characteristics, and apparent total tract macronutrient digestibility in domestic (n = 8) and captive exotic felids (n = 4) fed beef-, bison-, elk-, and horsemeat-based raw diets[1]

	Diet					*P*-value		
Item	Beef	Bison	Elk	Horse	SEM	Diet	Species	Diet × species
Intake, g DM/d/kg BW$^{0.75}$						< 0.01	< 0.01	< 0.01
African wildcat	18.5^{x}	22.2^{x}	18.5^{x}	22.1^{x,y}	1.9			
Domestic cat	18.7^{a,b,x}	20.6^{b,x}	20.5^{b,x}	15.9^{a,x}	1.3			
Jaguar	24.7^{a,b,x,y}	28.2^{b,x,y}	22.9^{a,x,y}	26.3^{a,b,y,z}	1.9			
Malayan tiger	30.6^{a,b,y}	34.9^{b,y}	30.2^{a,y}	33.2^{a,b,z}	1.9			
Output, g DM/d						0.01	< 0.01	0.01
African wildcat	2.4^{x}	3.1^{x,y}	2.7^{x}	2.7^{x}	0.4			
Domestic cat	2.9^{a,b,x}	2.5^{a,b,x}	3.2^{b,x}	2.0^{a,x}	0.3			
Jaguar	3.5^{x,y}	4.6^{y,z}	3.3^{x,y}	3.5^{x,y}	0.4			
Malayan tiger	4.8^{y}	5.5^{z}	4.9^{y}	4.8^{y}	0.4			
Fecal DM, %						0.16	< 0.01	0.25
African wildcat ^{x}	56.5	54.2	57.6	51.4	2.3			
Domestic cat ^{x}	54.1	59.4	62.5	60.1	1.7			
Jaguar ^{y}	42.5	43.0	45.0	41.9	2.3			
Malayan tiger ^{z}	37.7	37.8	37.6	39.1	2.3			
Fecal score						0.04	< 0.01	< 0.01
African wildcat	2.2	2.4^{x,y}	2.1^{x}	2.7^{y}	0.2			
Domestic cat	2.2^{a}	2.0^{a,b,x}	1.8^{a,b,x}	1.7^{b,x}	0.2			
Jaguar	2.8	2.7^{x,y}	2.8^{x,y}	3.1^{y}	0.2			
Malayan tiger	3.0	3.1^{y}	3.2^{y}	3.6^{y}	0.2			
DM digestibility, %						0.30	0.17	0.13
African wildcat	87.2	86.5	85.8	88.1	1.4			
Domestic cat	84.1	88.1	84.3	87.1	1.1			
Jaguar	87.0	83.6	86.0	86.3	1.4			
Malayan tiger	84.2	84.7	84.6	85.7	1.5			
OM digestibility, %						0.30	0.09	0.10
African wildcat	89.8	89.0	89.2	90.6	1.2			
Domestic cat	87.4	90.4	87.7	89.8	0.9			
Jaguar	89.8	86.0	88.7	88.9	1.2			
Malayan tiger	86.7	86.9	88.0	88.3	1.3			
CP digestibility, %						< 0.01	< 0.01	0.31
African wildcat ^{y}	97.2^{b,c}	96.3^{a}	97.5^{c}	96.3^{a,b}	0.4			
Domestic cat ^{y}	96.6^{b,c}	96.8^{a}	97.3^{c}	96.8^{a,b}	0.3			
Jaguar ^{xy}	96.9^{b,c}	95.6^{a}	97.3^{c}	96.1^{a,b}	0.5			
Malayan tiger ^{x}	95.2^{b,c}	94.3^{a}	96.3^{c}	95.2^{a,b}	0.5			
Fat digestibility, %						< 0.01	0.03	< 0.01
African wildcat	95.0	95.9^{y,z}	90.5	95.6	1.6			
Domestic cat	95.0^{b}	96.8^{b,z}	88.8^{a}	97.2^{b}	1.0			
Jaguar	93.8^{a,b}	87.2^{a,x}	89.3^{a}	96.3^{b}	1.5			
Malayan tiger	90.5	92.1^{x,y}	88.3	93.8	1.5			
GE digestibility, %						0.11	0.05	0.02
African wildcat	92.3	90.9	91.1	92.5	1.1			
Domestic cat	90.3	92.7	89.9	92.2	0.8			
Jaguar	92.0	87.3	90.8	91.2	1.1			
Malayan tiger	88.9	89.2	89.7	90.2	1.2			

[a-c]Means within a row lacking a common superscript letter are different ($P \leq 0.05$).

[x-z]Means within a column lacking a common superscript letter are different ($P \leq 0.05$); and overall means for species within the first column lacking a common superscript differ ($P \leq 0.05$).

[1]Fecal scores based on this scale: 1 = hard, dry pellets; 2 = dry, well-formed stools; 3 = soft, moist, formed stool; 4 = soft, unformed stool; and 5 = watery, liquid that can be poured.

Table 6. Fecal characteristics of domestic cats ($n = 8$) fed beef-, bison-, elk-, and horsemeat-based raw diets (DM basis)[1]

	Diet					
Item	Beef	Bison	Elk	Horse	SEM	*P*-value
pH	7.16[a,b]	6.89[a]	7.23[b]	7.12[a,b]	0.11	0.03
Ammonia, umol/g	221.57	253.47	255.51	214.29	23.37	0.38
Phenol, umol/g	0.07	0.07	0.11	0.11	0.07	0.74
Indole, umol/g	0.28	0.46	0.54	0.49	0.08	0.08
Total SCFA, umol/g	112.65	91.14	101.69	84.03	10.37	0.16
Acetate	79.69	65.47	68.71	58.78	7.43	0.15
Butyrate	13.83	11.69	15.45	12.28	1.21	0.21
Propionate	19.12	13.98	17.54	12.97	2.16	0.09
Total BCFA, umol/g	15.60[b]	11.15[a]	15.12[b]	14.39[a,b]	1.06	0.01
Isobutyrate	3.51	2.99	3.70	3.22	0.28	0.15
Isovalerate	5.14	4.45	5.93	5.35	0.45	0.13
Valerate	6.94[b]	3.71[a]	5.80[a,b]	5.82[a,b]	0.62	0.01
Microbes, log cfu/g						
Lactobacillus genus	10.04[a,b]	10.21[b]	9.79[a]	10.08[a,b]	0.95	0.01
Bifidobacterium genus	6.01	6.04	5.84	6.01	0.07	0.16
Clostridium perfringens	10.41	10.51	10.57	10.40	0.13	0.67
Escherichia coli	10.01	10.34	9.98	9.96	0.16	0.29

[a,b]Means within a row lacking a common superscript letter are different ($P \leq 0.05$).

[1]SCFA (short-chain fatty acids) = acetate + butyrate + propionate; and BCFA (branched-chin fatty acids = isobutyrate + isovalerate + valerate.

Fecal Characteristics

Fresh fecal characteristics were determined using data only from domestic cats. Fecal concentrations of total BCFA (isobutyrate + valerate + isovalerate) were greater ($P \leq 0.05$) in cats fed elk and beef as compared with those fed bison (Table 6). Fecal valerate concentrations were greater ($P \leq 0.05$) in cats fed beef as compared with those fed bison. The proportion of fecal acetate was greater ($P \leq 0.05$) for cats fed bison (72.06%) as compared with cats fed elk (67.22%; data not shown). The proportion of fecal butyrate was greater ($P \leq 0.05$) for cats fed elk (15.64%) as compared with those fed bison (13.03%) and beef (12.64%; data not shown). The proportion of propionate was not affected by dietary treatment (15 to 17%; data not shown). Fecal pH was greater ($P \leq 0.05$) in cats fed elk as compared with those fed bison. The fecal concentration of *Lactobacillus* genus was greater ($P \leq 0.05$) in cats fed bison as compared with those fed elk. Fecal concentrations of ammonia, total SCFA (acetate + butyrate + propionate), acetate, butyrate, propionate, isobutyrate, isovalerate, phenol, indole, *Bifidobacterium* genus, *C. perfringens*, and *E. coli* were not affected by diet.

Blood Metabolites

Blood metabolite concentrations of domestic cats and reference ranges are presented in Table 7. Serum sodium concentrations were greater ($P \leq 0.05$) than reference values in cats fed horse (156.3 mmol Na/L). Serum alanine amino transferase (**ALT**) concentrations were greater ($P \leq 0.05$) than reference values in cats fed beef, elk, and horse (68.1, 67.3, and 62.0 U ALT/L). Although some serum metabolite concentrations were numerically above the reference range values, the remaining metabolites did not differ from reference ranges, and there were few differences due to dietary treatment.

DISCUSSION

Our objective was to evaluate traditional and alternative raw meat sources for use in commercial and zoo prepared diets for captive exotic felids, and for use in homemade raw meat diets for domestic cats. Raw meat sources have not been adequately studied in felids. Additionally, fatty acid, protein, and AA compositional and bioavailability data are needed to develop dietary formulations that meet nutrient requirements.

Meat trimmings are readily available protein and fat sources that are commonly included in commercial and zoo prepared diets for captive exotic felids, and are available for use in homemade raw meat diets for domestic carnivores. Trimmings are composed of excess tissue after slaughter; however, they are highly variable and can be high in fat. The use of muscle meat is more common in homemade diets, but the high volume required for exotic animals would be cost preventive. The protein source for the beef, bison, and horse diets were trimmings. The protein source for the elk diet was composed of muscle meat. Despite the simple ingredient composition of the diets, variation in the protein sources resulted in highly variable nutrient composition. Thus,

Table 7. Food-restricted blood metabolite concentrations of domestic cats (n = 8) fed beef-, bison-, elk-, and horse-meat-based raw diets

	Diet						
Item	Beef	Bison	Elk	Horse	SEM	P-value	Reference range[2]
Urea nitrogen, mg/dL	30.6[a,b]	27.7[a]	31.7[b]	29.5[a,b]	1.2	0.03	15.4 to 31.2
Total protein, g/dL	7.2	7.1	7.3	7.0	0.2	0.20	5.7 to 8.0
Albumin, g/dL	3.8	3.7	3.8	3.7	0.1	0.87	2.4 to 3.7
Calcium, mg/dL	10.0	9.7	9.8	10.0	0.2	0.30	7.9 to 10.9
Phosphorus, mg/dL	5.2[a,b]	5.2[a,b]	5.3[b]	4.9[a]	0.2	0.03	4.0 to 7.3
Sodium, mmol/L	155.3[a,b]	154.6[a,b]	152.5[b]	156.3[a]	1.0	0.05	140.3 to 153.9
Potassium, mmol/L	4.7[a,b]	4.7[a]	5.0[b]	4.8[a,b]	0.1	0.02	3.8 to 5.3
Chloride, mmol/L	118.0[a,b]	117.5[a,b]	116.6[b]	119.5[a]	0.8	0.05	107.5 to 129.6
Glucose, mg/dL	75.5	80.0	74.0	78.4	3.4	0.41	60.8 to 124.2
ALT[1], U/L	68.1[b]	54.9[a]	67.3[b]	62.0[a,b]	4.1	0.05	8.3 to 52.5
Cholesterol, mg/dL	163.1[a,b]	150.6[a]	144.9[a]	173.3[b]	6.9	< 0.01	71.3 to 161.2
Bicarbonate, mmol/L	17.7[a,b]	17.8[a,b]	17.2[a]	19.0[b]	0.5	0.02	16.4 to 22.0
Creatinine, mg/dL	1.6	1.6	1.6	1.8	0.1	0.10	0.5 to 1.9
NEFA, mEq/L	0.6	0.6	0.6	0.7	0.1	0.27	NA[3]
Triglycerides, mg/dL	33.9[a,b]	30.0[a]	39.3[b]	34.3[a,b]	2.2	0.01	8.9 to 71.2[4]

[a,b]Means within a row lacking a common superscript letter are different ($P \leq 0.05$).

[1]ALT = Alanine aminotransferase.

[2]Merck (2005).

[3]NA = None available.

[4]Kluger et al. (2009).

differences because of diet cannot be attributed to protein source or macronutrient composition alone.

Macronutrient Composition

Each diet consisted mainly of the raw meat source (96.8%); thus, dietary compositional data likely reflects the raw meat composition. All diets fed herein contained similar DM (25 to 43%), OM (84 to 96%), and CP (41 to 84%) concentrations to raw meat based diets fed to captive exotic felids in previous studies (Vester et al., 2010a,b; Kerr et al., 2012). The beef, bison, and horse diets had similar fat concentrations (9 to 37% of DM; Vester et al., 2010a,b; Kerr et al., 2012). The muscle meat of the elk diet, however, was over-trimmed, and the resulting fat concentration (6.5%) was less than our estimates and the requirements for domestic cats (90 g/kg DM for diets with 4,000 kcal ME/kg DM; NRC, 2006). These data indicate that when muscle meats are used as the primary protein source, additional fat source may be necessary. Macronutrient composition of all diets was within the ranges reported for pet ingredients of animal origin (NRC, 2006).

Long-Chain Fatty Acid Composition

Examinations of fatty acid profiles with specific interest to relative and total amounts of SFA, PUFA, and essential fatty acids in large animals (i.e., raw meat sources) have been reported; however, fatty acid profiles can be affected by many factors, including tissue (muscle vs. adipose), fat depot, animal species, diet, breed, sex, age, and environment (Turner, 2005). Literature has focused on muscle meat quality and tissue depot differences. Because trimmings are composed of a mixture of intramuscular and intermuscular fat tissues, and dietary information of the animals is unknown, it is likely that generalizations regarding trends in fat composition will not be true when examining trimmings. Although species-specific differences have been noted in intramuscular fat composition between beef and bison species, the beef and bison diets (i.e., ruminant species) had the most similar pattern of fat composition in this study. This was likely due to the greater amount of intermuscular fat, which has been noted to be similar between these species (Turner, 2005). All diets had similar proportion of total fatty acids as SFA (42 to 45%). Ruminants deposit greater amounts of SFA and MUFA in their tissues than contained in their diets, so it is not surprising that the beef and bison diets had numerically greater MUFA concentrations than elk and horse diets (43 and 44% vs. 30 and 36%, respectively). Because the elk diet was mainly muscle tissue, the greater proportion of PUFA (10%) as compared with beef, bison, and horse (3%) may be due to the increased amount of phospholipids in intramuscular fat as compared with intermuscular fat.

Cats, like all mammals, require LA (n-6) in their diet. Because of low activity of Δ6 desaturase (Davidson et al., 1986; Pawlosky et al., 1994; Bauer, 1997), cats may have a conditional requirement for dietary ARA (n-6), EPA (n-3), and DHA (n-3; Morris, 2004). Additionally,

ALA (n-3) recommendations are provided for kittens after weaning, and during gestation and lactation (NRC, 2006). No studies have been performed to determine the absolute requirements of long-chain PUFA in the cat. All diets fed herein were adequate sources of ALA; however, for all lifestages, none met the recommended levels of LA. The elk and horse diets were also less than the combined recommendation for EPA and DHA. The horse diet had less ARA than that recommended for kittens, gestation, and lactation.

Amino Acid Composition and the Rooster Assay

Amino acid compositional and bioavailability data are needed to allow the development of dietary formulas that meet nutrient requirements. Amino acid deficiencies and imbalances can impair health, growth, and reproduction. Dietary CP concentration and AA composition data are the first step to understanding the quality of a protein. The first LAA for all diets was the combined requirement for methionine and cysteine. In addition, for all diets the combined requirement for phenylalanine and tyrosine also scored below 100. The AAS reported herein are not surprising when you consider animal origin pet food ingredients. Based on the published composition of selected pet food ingredients of animal origin in the NRC (2006) and using the minimum requirement for growth of kittens, AAS values for animal origin protein sources ranged from 61 to 100. The first LAA was either combined requirement for Met and Cys (AAS: 61 to 100) or the combined requirement for Phe and Tyr (AAS: 71 to 96). Examination of additional published compositional data returns similar results for a majority of ingredients (Murray et al., 1997; Johnson et al., 1998; Dozier et al., 2003; Folador et al., 2006; Cramer et al., 2007; Faber et al., 2010; USDA, 2011).

Determining the bioavailability of individual AA allows for improved feed formulation. The precision-fed cecectomized rooster assay is used extensively for determining AA digestibility of feed ingredients. Cecectomy allows for digestibility estimates to be made without the confounding effect of microbial fermentation and protein from the ceca of the birds, and requires less time and monetary commitment than ileal cannulation assays. It has been used to examine both animal and plant protein sources for use in pet foods (Johnson et al., 1998; Folador et al., 2006; de Godoy et al., 2009; Faber et al., 2010). Johnson et al. (1998) directly compared the cecectomized rooster assay and the ileal-cannulated dog assay, and reported that it was appropriate for predicting variation in AA digestibility among animal meals for dogs. The authors are aware of no direct comparison with the ileal-cannulated cat assay; however, for proteins with greater than 90% protein digestibility, it is generally accepted that there is no difference between cats and dogs (Kendall et al., 1982).

The cecectomized rooster results reported herein indicate that standardized AA digestibility was high for all diets. Values for individual AA, TAA, TIAA, and TDAA were greater than reported for meat and bone, lamb, and poultry by-product meals (62 to 82% TAA digestibility; Johnson et al., 1998; Wang and Parsons, 1998); however, similar to values reported for fish by-products, fish meals, and fish substrates (86 to 92% TAA digestibility; Folador et al., 2006; Faber et al., 2010). Processing technique and connective tissue content may affect AA digestibility (Batterham et al., 1986; Wang and Parsons, 1998). Because the diets were fed raw, there was no decrease in digestibility due to heat exposure or other processing techniques. Although there were differences in connective tissue between diets, they did not negatively affect AA digestibility in the present study.

Apparent Total Tract Macronutrient Digestibility

Intake and fecal output on a metabolic BW basis were influenced by both diet and species, with tigers eating and defecating more than domestics and wildcats, whereas jaguars had intermediate values. The differences in diet composition between diets resulted in DMI differences among the diets.

Digestibility of raw meat-based diets appears to depend on species; however, few interactions have been reported between diet and species for diet digestibility (Vester et al., 2010a). The data presented herein may have also been impacted by sex or age. All African wildcats and domestic cats used were young to middle-aged adults (2 to 4 yr), whereas a wider range of jaguars (2 to 19 yr) and Malayan tigers (3 to 13 yr) was used. Domestic cats were all female, and Malayan tigers were predominantly female (1 male, 3 female), whereas jaguars were predominantly male (3 male, 1 female).

Reported values for apparent digestibilities are highly variable (DM: 66 to 89%; Vester et al., 2010a, 2010b). Macronutrient and energy digestibility values in this study were at the high ranges reported for exotic felids and few differences among species were observed. This outcome was likely due to the simple nature of our diets (i.e., composed of only raw meat, vitamin-mineral premix, and fiber source).

Because of the greater number of animals ($n = 8$), differences in fat digestibility for domestics may have been more pronounced (i.e., elk diet had decreased fat digestibility compared with the other diets), whereas no differences were observed in captive exotic species. Because most of the fat in the elk meat source was trimmed off, there was little intermuscular fat in the diet, meaning that less available forms of fat (e.g., intramuscular fat or fatty

acids from phospholipids) likely made up a greater percentage of the dietary fat. Additionally, because the dietary fat concentration was low, endogenous fat excretion and losses during fat analysis would impact digestibility calculations greater than in diets greater in fat. Kane et al. (1981) reported similar results, with increased total tract fat digestibility observed in domestic cats fed diets containing 25 and 50% DM as fat (97 to 99%) as compared with those fed diets with 10% DM as fat (90%). Similarly, Davidson et al. (1978) reported that a diet composed of snowshoe hare (3.7% dietary fat) had a decreased fat digestibility (81%) when compared with other whole prey diets (9 to 40% dietary fat; 92 to 99% digestibility) when fed to fishers. Reported values for CP digestibility in domestic and captive exotic species are variable (73 to 96% CP digestibility); however, more recent trials, including the one reported herein, indicate that raw meat sources can be highly digestible (90 to 97% CP digestibility; Vester et al., 2010a,b; Kerr et al., 2012). The CP digestibility values reported herein agree with the rooster AA digestibility, and indicate very high digestibility of the protein. In addition to high digestibility, the diets fed herein also maintained positive N balance (0.36 to 1.21 g N/d) in domestic cats (Kerr et al., 2011). Differences among species were noted for CP digestibility; however, in regards to protein quality these differences (<2% units difference) are likely biologically insignificant. In this study, it appears that the smaller species have increased digestive capacity compared with larger animals; however, further research would be necessary to determine if BW or size may impact CP digestibility. Vester et al. (2010a) reported differences in CP digestibility with increased digestibility in smaller species, whereas Vester et al. (2008) found no differences between species. The differences observed among diets were likely due to differences between ingredient composition. Compared with the elk diet, diets that contained trimmings had less available forms of protein (e.g., connective tissues containing collagen) making up a greater percentage of the dietary protein. Fermentation in the large bowel also impacts apparent total tract CP digestibility, and must be considered. When CP digestibility is decreased, an increased amount of protein enters the large bowel and may be fermented by hindgut microbiota. This may lead to an increased production of bacterial protein, which will be excreted in the feces, thereby underestimating CP digestibility.

Metabolizable Energy

The NRC (2006) recommends using the Atwater values of 9, 4, and 4 kcal ME/g for fat, protein, and NFE, respectively, to estimate ME of unprocessed cat foods. Although this method (ME_E) slightly underestimated the ME calculated (ME_C) in the domestic cats for bison, elk and horse diets, the pattern between diets was similar for both methods. Therefore, the NRC (2006) method would have been appropriate for examining the difference between diets for domestic cats. Underestimation by this method of calculation is likely due to the simple nature of our diets and the high digestibility values, but may be more appropriate for more complex formulations. Because apparent total tract GE and CP digestibilities were impacted by species, it is important to note that dietary ME content may also differ because of species.

Fecal Characteristics

Fecal scores were influenced by both diet and felid species. Dietary impacts on fecal score were only observed in domestic cats, which may be due to the increased statistical power because of the increased number of animals used for this species. For differences among species, fecal score generally appeared to increase with body size. On our 5-point scale, with 3 being ideal, jaguars (2.8) and tigers (3.2) had ideal scores, whereas wildcats (2.3) and domestic cats (1.9) had firmer stools. Fecal DM data were consistent with these results. Vester et al. (2008, 2010a) reported similar fecal score and DM results for captive exotic and domestic cats fed commercial horsemeat- or beef-based diets with cellulose or beet pulp as the fiber source. The trend of poor fecal quality with larger body size has also been reported in dogs (small vs. large and giant breed dogs; Hernot et al., 2004, 2005, 2006; Weber et al., 2004). It has been suggested that the differences reported in dogs may be linked to longer transit time, increased intestinal permeability, or increased fermentative activity in the large bowel of large-breed dogs. However, research that examines these differences in felid species is limited.

Raw meat-based diets for domestic and captive exotic felids have high protein concentrations, which may increase the amount of protein reaching the hindgut and being fermented. The fermentative capacity of cats is generally thought to be limited because of the carnivorous diet of the cat and evolutionary impact of their diet on anatomical features of the gastrointestinal tract. It is well documented that indicators of protein fermentation (i.e., putrefactive compounds, including phenols, indoles, ammonia, and BCFA) exist in the feces of cats and can be quite high depending on diet (Terada et al., 1993; Vester et al., 2008, 2010a). Protein-related fermentative compounds are odiferous and have been linked to gastrointestinal disease in humans. Because raw meat-based diets are high in protein, it is important to limit the production of putrefactive compounds. Vester et al. (2010a) reported differences in fecal characteristics in domestic and exotic cats fed differing protein sources (beef- and horsemeat-based raw diets); however, because of addi-

tional differences in ingredient composition, including fiber source, it was unclear which differences could be attributed to protein source and which could be attributed to other dietary ingredients and interactions.

All diets fed herein used cellulose as a fiber source. Given the nonfermentable nature of this fiber, we expected concentrations of fermentative end-products to be low. Fecal concentrations of SCFA, BCFA, phenol, and indoles in the current study were similar to those reported for domestic cats fed raw meat-based diets with cellulose as a fiber source (Vester et al., 2010a; Kerr et al., 2012), but less than those fed raw meat and traditional extruded diets with beet pulp as a fiber source (Vester et al., 2010a,b; Kerr et al., 2012). Fecal concentrations of SCFA, BCFA, phenols, and indoles were less than those reported for captive exotic felids (246 to 1,689 umol SCFA/g DM feces; 19.8 to 202 μmol BCFA/g DM feces; Vester et al., 2008, 2010a). It is also worth noting that no differences in fecal characteristics were observed between cats fed horse and beef diets in this study, which indicates that the differences reported by Vester et al. (2010a) were likely due to other dietary ingredient differences or ingredient interactions.

Because of the simple ingredient composition herein, protein source was the primary substrate available for fermentation. Differences in dietary CP concentrations likely contributed to the differences observed in fermentative end-products of domestic cats in the present study. Given the similarities of total AA digestibility measured in cecectomized roosters, we expected increased dietary protein concentration and intake to result in an increased quantity of protein entering the large bowel. This would increase protein available for fermentation, and potentially increase indicators of protein fermentation, such as fecal pH and concentrations of ammonia, phenol, indole, and BCFA. Although fecal ammonia, phenol, and indole concentrations were not different, when compared with data for cats fed bison (the diet with least CP), cats fed elk (diet with greatest CP) had greater fecal pH and total BCFA concentrations, and cats fed horse (diet with second greatest CP) had greater fecal total BCFA concentrations.

The alterations to the gut environment because of high protein fermentation may cause shifts in microbial populations (Lubbs et al., 2009; Hooda et al., 2012). The decreased fecal concentrations of *Lactobacillus* genus, decreased acetate proportion, and increased butyrate proportion in cats fed elk (compared with those fed bison), are likely due to such microbial shifts. The potential to alter microbial species and fecal characteristics by dietary protein source and concentration may have implications for host health and warrants further investigation.

Blood Metabolites

Diagnostically, it is important to understand how feeding raw meat diets may impact serum chemistry. However, because of the paucity of data on blood metabolites reported in domestic cats fed raw meat (Kerr et al., 2012), it is unclear how the ingredient and macronutrient composition differences between raw meat-based diets and traditional diets can impact the serum profile. It is worth noting that some alterations in serum chemistry because of dietary changes can take longer than the length of this study to develop, and longer-term studies are needed to overcome this limitation.

Increased serum ALT concentrations can be diagnostically indicative of dysfunction or toxic insult of the liver (Merck, 2005). Alanine aminotransferase concentrations similar to those herein, and above the reference range provided have been reported in domestic cats (67.8 U/L; Kerr et al., 2012), African wildcats (79 U/L; Vester et al., 2010b), and dogs (23 to 112 U/L; Beloshapka, 2011) fed raw meat diets. Kerr et al. (2012) also reported increased serum albumin concentrations when cats were fed a raw meat diet (4.0 to 4.1 g/dL). Although not statistically different, serum albumin concentrations reported herein were at the upper end of the reference range in cats fed bison and horse, and slightly increased in cats fed beef and elk diets. Increased serum albumin has been associated with both high protein intakes and dehydration (Mutlu et al., 2006; Frantz, 2010; Backlund et al., 2011). Additionally, urea N, Na, and cholesterol values were also at the upper end of the reference ranges. The increased serum Na concentrations may be indicative of hemoconcentration, which may have also contributed to changes of the other metabolites. Hypernatremia can occur during dehydration. The diets fed herein had high moisture content and water was available ad libitum. These data may indicate that further research is warranted to determine if separate reference ranges may be necessary for animals fed raw diets and what the long-term health effects of these differences may be.

Conclusions

Nutrient analysis of raw meat sources is necessary for proper diet formulation. Although the raw meat diets studied herein were simple in ingredient composition and highly digestible, nutrient composition of the diets was variable. The types of raw meat commonly used in raw meat diets may be deficient in total fat (trimmed muscle meat) and essential fatty acids (trimmings and muscle meats), requiring additional fat sources or supplementation. The first LAA in trimmings was the combined requirement of Met and Cys and, thus, the concentration and digestibility of these AA should be considered.

Because of the variation in nutrient composition, differences because of diet cannot be attributed to protein source or macronutrient composition alone. Likely because of the simple nature of our diets (i.e., few extras), digestibility values were at the high ranges reported for exotic felids and few differences were observed among species. To determine species-specific differences, investigations may need to focus on less digestible dietary components, including fiber sources. Although diet affected the beneficial and putrefactive fermentative end-products present in feces, research is necessary to separate the effects of nutrient composition from meat source.

LITERATURE CITED

AACC. 1983. Approved methods. 8th ed. Am. Assoc. Cereal Chem., St. Paul, MN.

AOAC. 2006. Official methods of analysis. 17th ed. Assoc. Off. Anal. Chem., Arlington, VA.

Backlund, B., D. L. Zoran, M. B. Nabity, B. Norby, and J. E. Bauer. 2011. Effects of dietary protein content on renal parameters in normal cats. J. Feline Med. Surg. 13:698–704.

Batterham, E. S., R. E. Darnell, L. S. Herber, and E. J. Major. 1986. Effect of pressure and temperature on the availability of lysine in meat and bone meal as determined by slope-ratio assays with growing pigs, rats, chicks and by chemical techniques. Br. J. Nutr. 55:441–453.

Bauer, J. E. 1997. Fatty acid metabolism in domestic cats (*Felis catus*) and cheetahs (*Acinonyx jubatas*). Proc. Nutr. Soc. 56:1013–1024.

Beloshapka, A. N. 2011. Effects of inulin or yeast cell wall extract on nutrient digestibility and fecal fermentative end-product concentrations of healthy adult dogs fed raw diets. MS Thesis. Univ. of Illinois, Urbana, IL.

Budde, E. F. 1952. The determination of fat in baked biscuit type of dog foods. J. Assoc. Off. Agric. Chem. 35:799–805.

Chaney, A. L., and E. P. Marbach. 1962. Modified reagents for determination of urea and ammonia. Clin. Chem. 8:130–132.

Clauss, M., H. Kleffner, and E. Kienzle. 2010. Carnivorous mammals: Nutrient digestibility and energy evaluation. Zoo Biol. 29:687–704.

Cramer, K. R., M. W. Greenwood, J. S. Moritz, R. S. Beyer, and C. M. Parsons. 2007. Protein quality of various raw and rendered by-product meals commonly incorporated into companion animal diets. J. Anim. Sci. 85:3285–3293.

Davidson, B. C., R. C. Cantrill, and D. Varaday. 1986. The reversal of essential fatty acid deficiency symptoms in the cheetah. S. Afr. J. Zool. 21:161–164.

Davidson, R. P., W. W. Mautz, H. H. Hayes, and J. B. Houlter. 1978. The efficiency of food utilization and energy requirements of captive female fishers. J. Widl. Manage. 42:811–821.

deGodoy, M. R., L. L. Bauer, C. M. Parsons, and G. C. Fahey Jr. 2009. Select corn coproducts from the ethanol industry and their potential as ingredients in pet foods. J. Anim. Sci. 87:189–199.

Dozier, W. A., III, N. M. Dale, and C. R. Dove. 2003. Nutrient composition of feed-grade and pet-food grade poultry by-product meal. J. Appl. Poult. Res. 12:526–530.

Erwin, E. S., G. J. Marco, and E. M. Emery. 1961. Volatile fatty acid analyses of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768–1771.

Faber, T. A., P. J. Bechtel, D. C. Hernot, C. M. Parsons, K. S. Swanson, S. Smiley, and G. C. Fahey Jr. 2010. Protein digestibility evaluations of meat and fish substrates using laboratory, avian, and ileally cannulated dog assays. J. Anim. Sci. 88:1421–1432.

FAO/WHO/ÚNU Expert Consultation. 2007. Protein and Amino Acid Requirements in Human Nutrition. Energy and Protein Requirements. Tech. Rep. Ser. 935. World Health Organ., Geneva, Switzerland.

Flickinger, E. A., E. M. W. C. Schreijen, A. R. Patil, H. S. Hussein, C. M. Grieshop, N. R. Merchen, and G. C. Fahey Jr. 2003. Nutrient digestibilities, microbial populations, and protein catabolites as affected by fructan supplementation of dog diets. J. Anim. Sci. 81:2008–2018.

Folador, J. F., L. K. Karr-Lilienthal, C. M. Parsons, L. L. Bauer, P. L. Utterback, C. S. Schasteen, P. J. Bechtel, and G. C. Fahey Jr. 2006. Fish meals, fish components, and fish protein hydrolysates as potential ingredients in pet foods. J. Anim. Sci. 84:2752–2765.

Frantz, N. 2010. The effect of dietary crude protein and lysine:calorie ratio on body composition and kidney measures in healthy adult and geriatric cats. Proc. Am. Col. Vet. Int. Med. Forum. Anaheim, CA.

Hernot, D. C., V. C. Biourge, L. J. Martin, H. J. Dumon, and P. G. Nguyen. 2005. Relationship between total transit time and faecal quality in adult dogs differing in body size. J. Anim. Physiol. Anim. Nutr. (Berl.). 89:189–193.

Hernot, D. C., H. J. Dumon, V. C. Biourge, L. J. Martin, and P. G. Nguyen. 2006. Evaluation of association between body size and large intestinal transit time in healthy dogs. Am. J. Vet. Res. 67:342–347.

Hernot, D. C., M. P. Weber, V. C. Biourge, L. J. Martin, H. J. Dumon, and P. G. Nguyen. 2004. Relationship between electrolyte apparent absorption and fecal quality in adult dogs differing in body size. J. Nutr. 134:2031S–2034S.

Hooda, S., B. M. Vester Boler, K. R. Kerr, S. E. Dowd, and K. S. Swanson. 2012. The gut microbiome of kittens is affected by dietary protein: Carbohydrate ratio and correlated with blood metabolite and hormone concentrations. Br. J. Nutr. (In press.) doi: 10.1017/S0007114512003479.

Johnson, M. L., C. M. Parsons, G. C. Fahey Jr., N. R. Merchen, and C. G. Aldrich. 1998. Effects of species raw material source, ash content, and processing temperature on amino acid digestibility of animal by-product meals by cecectomized roosters and ileally cannulated dogs. J. Anim. Sci. 76:1112–1122.

Kane, E., J. G. Morris, and Q. R. Rogers. 1981. Acceptability and digestibility by adult cats of diets made with various sources and levels of fat. J. Anim. Sci. 53:1516-1523.

Kendall, P. T., D. W. Holme, and P. M. Smith. 1982. Comparative evaluation of net digestive and absorptive efficiency in dogs and cats fed a variety of contrasting diet types. J. Small Anim. Pract. 23:577–587.

Kerr, K. R., A. N. Beloshapka, C. L. Morris, and K. S. Swanson. 2011. Nitrogen metabolism of four raw meat diets in domestic cats. Br. J. Nutr. 106: S174–S177.

Kerr, K. R., B. M. Vester, C. L. Morris, K. J. Liu, and K. S. Swanson. 2012. Apparent total tract energy and macronutrient digestibility and fecal fermentative end-product concentrations of domestic cats fed extruded, raw beef-based and cooked beef-based diets. J. Anim. Sci. 90:515–522.

Kluger, E. K., C. Hardman, M. Govendir, R. M. Baral, D. R. Sullivan, D. Snow, and R. Malik. 2009. Triglyceride response following and oral fat tolerance test in Burmese cats, other pedigree cats and domestic crossbred cats. J. Feline Med. Surg. 11:82–90.

Lepage, G., and C. C. Roy. 1986. Direct transesterification of all classes of lipids in a one-step reaction. J. Lipid Res. 27:114–120.

Lubbs, D. C., B. M. Vester, N. D. Fastinger, and K. S. Swanson. 2009. Dietary protein concentration affects intestinal microbiota of adult cats: A study using DGGE and qPCR to evaluate differences in microbial populations in the feline gastrointestinal tract. J. Anim. Physiol. Anim. Nutr. (Berl.). 93:113–21.

Merck. 2005. Merck veterinary manual. 9th ed. C. M. Kahn, editor. Merck & Co., Whitehouse Station, NJ.

Middelbos, I. S., M. R. Godoy, N. D. Fastinger, and G. C. Fahey Jr. 2007. A dose-response evaluation of spray-dried yeast cell wall supplementation of diets fed to adult dogs: Effects on nutrient digestibility, immune indices, and fecal microbial populations. J. Anim. Sci. 85:3022–3032.

Morris, J. G. 2004. Do cats need arachidonic acid in the diet for reproduction? J. Anim. Physiol. Anim. Nutr. (Berl.). 88:131–137.

Murray, S. M., A. R. Patil, G. C. Fahey Jr., N. R. Merchen, and D. M. Hughes. 1997. Raw and rendered animal by-products as ingredients in dog diets. J. Anim. Sci. 75:2497–2505.

Mutlu, E. A., A. Keshavarzian, and G. M. Mutlu. 2006. Hyperalbuminemia and elevate transaminases associated with high-protein diet. Scand. J. Gastroenterol. 41:759–760.

NRC. 2006. Nutrient requirements of dogs and cats. Natl. Acad. Press. Washington, DC.

Pawlosky, R., A. Barnes, and N. Salem Jr. 1994. Essential fatty acid metabolism in the feline: Relationship between liver and brain production of long-chain polyunsaturated fatty acids. J. Lipid Res. 35:2032–2040.

Prosky, L., N. G. Asp, T. F. Schweizer, J. W. DeVries, I. Fruda, and S. C. Lee. 1994. Determination of soluble dietary fiber in foods and food products: Collaborative study. J. AOAC Int. 77:690–694.

Sibbald, I. R. 1979. A bioassay for available amino acids and true metabolizable energy in feedstuffs. Poult. Sci. 58:668–673.

Terada, A., H. Hara, S. Kato, T. Kimura, I Fujimori, K. Hara, T. Maruyama, and T. Mitosuoka. 1993. Effect of lactosucrose (4^{G}-β-D-galactossylsucrose) on fecal flora and fecal putrefactive products of cats. J. Vet. Med. Sci. 55:291–295.

Turner, T. D. 2005. Evaluation of the effect of dietary forage and concentrate levels on the fatty acid profile of bison tissue. MS Thesis. Univ. of Saskatchewan, Saskatoon, SK, Canada.

USDA. 2011. USDA national nutrient database for standard reference. http://www.nal.usda.gov/fnic/foodcomp/search/. (Accessed 20 September 2011.)

Wang, X., and C. M. Parsons. 1998. Dietary formulation with meat and bone meal on a total versus digestible or bioavailable amino acid basis. Poult. Sci. 77:1010–1015.

Weber, M. P., D. Hernot, P. G. Nguyen, V. C. Biourge, and H. J. Dumon. 2004. Effect of size on electrolyte apparent absorption rates and fermentative activity in dogs. J. Anim. Physiol. Anim. Nutr. (Berl.). 88:356–365.

Vester, B. M., A. N. Beloshapka, I. S. Middelbos, S. L. Burke, C. L. Dikeman, L. G. Simmons, and K. S. Swanson. 2010a. Evaluation of nutrient digestibility and fecal characteristics of exotic felids fed horse- or beef-based diets: Use of the domestic cat as a model for exotic felids. Zoo Biol. 29:432–448.

Vester, B. M., S. L. Burke, C. L. Dikeman, L. G. Simmons, and K. S. Swanson. 2008. Nutrient digestibility and fecal characteristics are different among captive exotic felids fed a beef-based raw diet. Zoo Biol. 27:126–136.

Vester, B. M., S. L. Burke, C. L. Dikeman, L. G. Simmons, and K. S. Swanson. 2010b. Influence of feeding raw or extruded feline diets on apparent total tract nutrient digestibility and nitrogen metabolism of African wildcats. Zoo Biol. 29:676–686.