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Influence of pork and pork by-products on macronutrient and energy digestibility and palatability in large exotic felids

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ABSTRACT: Two experiments were conducted to evaluate digestibility and palatability of a new commercial pork-based raw diet for zoo-managed felids. Currently 2 protein sources (beef or horse) comprise the majority of commercial raw meat diet formulations for exotic carnivores in zoological institutions. Pork-based diets have traditionally not been widely utilized and thus nutrient digestibility of pork has not been adequately evaluated in exotic carnivores. The objectives of this study were 1) to determine if a pork-based diet had similar apparent total tract macronutrient digestibility and fecal scores as standard zoo carnivore diets formulated with either horse or beef, in large exotic felids and 2) evaluate palatability of pork for use in zoos. Ten exotic felids were used including cheetahs (*Acinonyx jubatus*; $n = 3$), jaguars (*Panthera onca*; $n = 3$), leopards (*Panthera pardus*; $n = 2$), puma (*Puma concolor*; $n = 1$), and Bengal tiger (*Panthera tigris tigris*; $n = 1$). Dietary treatments consisted of 4 raw meat diets: 1 horse-based (Horse), 2 beef-based (B1, B2), and 1 pork-based diet (Pork). Fecal scores also were evaluated (1 = hard to 5 = watery/liquid). This randomized crossover design study consisted of 4 periods, each 10 d for treatment adaptation followed by 4 d of sample collection. Dry matter and crude protein apparent digestibility values were greater ($P < 0.05$) in felids fed Pork (88.0 and 95.7%) compared with felids fed Horse (83.6 and 92.7%) and B2 (85.6 and 93.1%). Apparent organic matter digestibility was greater ($P < 0.05$) in felids fed Pork (90.8%) than felids fed Horse (88.5%). Apparent fat digestibility values were high across all treatments but were greater ($P < 0.05$) in felids fed Pork (98.5%) compared with felids fed B1 (95.5%) or B2 (96.5%). Gross energy digestibility values were greater in felids fed Pork (92.4%) compared with B1 (90.2%). Average fecal scores were 2.30, 2.94, 3.42, and 3.54 for Horse, Pork, B1 and B2, respectively; and were different ($P < 0.05$) between treatments with exception of B1 and B2 that did not differ. Felids approached the pork diet first in 65.6% of observations and tasted the pork diet first in 71.9% of observations, compared with a beef-based raw diet. Based on results, the evaluated pork-based diet had similar apparent total tract macronutrient digestibility and palatability compared with standard zoo carnivore formulations. In conclusion, pork-based diets could be included among dietary options for large zoo felids.

Key words: exotic felids, fecal scores, nutrient digestibility, palatability, pork, raw diet

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INTRODUCTION

In zoological institutions, carnivores are typically fed raw meat diets manufactured with beef or horsemeat as primary protein sources. Although research studies addressing health benefits of raw meat diets in felids are lacking, several studies have documented greater digestibility of macronutrients in felid species fed various raw meat diets including beef, horse, and poultry compared with kibble diets (Wynne, 1989; Crissey et al., 1997; Vester et al., 2008; Vester et al., 2010a, 2010b; Kerr, 2012; Kerr et al., 2013). However, pork has not been evaluated for use in zoo carnivore diets and may provide a protein option for nutritional management of zoo carnivores. It is important to evaluate fecal scores, digestibility, and palatability of new dietary options to determine feasibility of incorporating them into animal management plans. Additionally, felids as a whole can develop aversions to foods comprising the majority of their diets for extended periods

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of time, known as the monotony effect. They may also develop an aversion to foods never consumed before, known as neophobia (Bradshaw, 2006). Therefore, appropriate evaluation of new dietary options is critical for management decisions.

The objectives of this study were to determine the apparent total tract macronutrient digestibility, fecal scores, and palatability of a new pork-based diet compared to standard zoological carnivore diets formulated with either beef or horse, in large exotic zoo-managed felids. This pork-based diet has never been evaluated and we hypothesized that the pork-based diet would have similar nutrient digestibility and palatability as typical beef or horse-based raw meat diets; therefore, could be included among dietary options utilized in zoos.

MATERIALS AND METHODS

All animal procedures were approved by Omaha's Henry Doorly Zoo & Aquarium's (**HDZ**) Animal Care and Use Committee (**IACUC**) before animal experimentation.

Experiment 1

Animals and Diets. Ten exotic felids were used (7 male, 3 female), ranging in age from 7 to 17 yr and weight from 36 to 100 kg, including cheetahs (*Acinonyx jubatus*; $n = 3$), jaguars (*Panthera onca*; $n = 3$), leopards (*Panthera pardus*; $n = 2$), puma (*Puma concolor;* $n = 1$), and Bengal tiger (*Panthera tigris tigris;* $n = 1$), all of which had been receiving the same raw beef-based diet before the study for at least 6 mo. Felids were individually housed in indoor or outdoor enclosures ranging from 49 to 151 m^3 at HDZ (Omaha, NE) and cared for by zoo staff. Water was provided ad libitum throughout the study. All dietary treatments were fed isocalorically daily to maintain individual animal body condition based on previous diet caloric intakes.

Four commercially prepared raw meat-based dietary treatments were analyzed for chemical composition and evaluation (Table 1). All diets were formulated to meet or exceed nutrient requirements of domestic felids (NRC, 2006). Dietary treatments consisted of 1 horse-based (Nebraska Brand: Premium Feline Diet [Horse] Central Nebraska Packing Inc., North Platte, NE), 2 beef-based (Natural Balance: Zoo Carnivore Diet [B1], Natural Balance Pet Foods, Inc., Burbank, CA and Nebraska-Brand: Special Beef Feline Diet [B2], Central Nebraska Packing Inc.), and one pork-based (Carnivore Essentials [Pork]. Sustainable Swine Resources, LLC., Sheboygan Falls, WI). Ingredients of dietary treatments are listed in Table 2. Each dietary treatment was subsampled, dried at 55°C, ground through a 2-mm screen (Wiley mill 3379-K35, Thomas Scientific, Swedesboro, NJ) and analyzed for chemical composition. All chemical analyses were conducted at Iowa State University unless otherwise noted. Dietary treatments were analyzed for DM (Method 934.01) and OM (Method 942.05 [AOAC, 2006]). Crude protein was determined using a Leco Nitrogen/Protein Determinator (Method 992.15; model TruMacN, Leco Corporation, St. Joseph, MI). Fat concentrations were determined by hexane extraction (Method 960.39 [AOAC, 2000]). Gross energy was determined by bomb calorimetry (model 6200, Parr Instrument Co., Moline, IL). Crude fiber (**CF**) was analyzed at Midwest Laboratories (Omaha, NE; AOCS Ba6a-05, [Thiex, 2008)]). Total dietary fiber (**TDF**) was determined at HDZ (Prosky et al., 1994) and assay methods were adjusted using triple the amount of protease and double the time for the water bath after addition of the protease for high protein samples.

Table 1. Chemical composition of raw meat diets fed to captive large exotic felids (DM basis)

Item[1]	Pork	Horse	B1[2]	B2[3]
DM, %	31.7	35.6	32.8	32.2
OM, %	94.6	92.3	92.0	93.1
CP, %	58.5	53.3	58.0	51.9
Fat, %	29.0	31.0	31.0	35.8
NFE, %	1.4	0.7	0.0	0.0
CF, %	2.4	3.1	3.5	2.3
TDF, %	5.6	7.3	7.9	5.5
GE, kcal/g	6.2	6.0	6.1	6.4

[1]NFE = nitrogen-free extract; CF = crude fiber; TDF = total dietary fiber.
[2]B1 = beef diet 1.
[3]B2 = beef diet 2.

Experimental Design. The experimental design was a randomized crossover design consisting of 4 dietary treatments each period, resulting in every felid receiving each diet for 1 period. Each of the 4 treatment periods consisted of 10 d for treatment adaptation followed by 4 d of sample collection. During each day of collection, total food intake was recorded and total fecal outputs were collected, weighed, and recorded. Additionally, feces were scored for each individual. Feces were evaluated by the lead author using a scale designed for exotic felids consisting of 1 to 5 where: 1 = hard, dry pellets; 2 = dry, well-formed; 3 = soft, moist, formed; 4 = soft, unformed; 5 = watery liquid (Felid Taxon Advisory Group, 2014).

Digestibility Procedures. Total fecal samples were collected, weighed, and scored daily for each felid then pooled for each collection period and subsampled to measure apparent total tract digestibility. Fecal samples were dried at 55°C and ground through a 2-mm screen (Wiley mill 3379-K35, Thomas Scientific). All fecal samples were analyzed for DM, OM, CP, GE, and fat concentrations using methods previously described for diet analy-

Table 2. Ingredient composition of a raw meat diets fed to captive large exotic felids

Diet	Ingredient composition
Pork: Carnivore Essentials (Sustainable Swine Resources, LLC., Sheboygan Falls, WI)	Pork, pork by-products, vitamins (beet pulp, cellulose, calcium carbonate, rice hulls, sodium chloride, mineral oil, vitamin E supplement, d-α-tocopheryl acetate (source of natural vitamin E), biotin, niacin supplement, thiamine mononitrate, vitamin B_{12} supplement, vitamin A acetate, vitamin D_3 supplement, pyridoxine hydrochloride, riboflavin supplement, d-calcium pantothenate, folic acid), minerals (beet pulp, cellulose, calcium carbonate, rice hulls, mineral oil, choline chloride, calcium phosphate, magnesium oxide, potassium chloride, ferrous sulfate, zinc sulfate, copper sulfate, manganese sulfate, zinc oxide, sodium selenite, cobalt carbonate, calcium iodate)
Horse: Nebraska Brand: Premium Feline (Central Nebraska Packing Inc., North Platte, NE)	Horsemeat, powdered cellulose, dicalcium phosphate, calcium carbonate, vitamin premix (roughage products, vitamin E supplement, mineral oil, niacin supplement, biotin, menadione sodium bisulfite complex [source of vitamin K activity], vitamin A supplement, riboflavin, pyridoxine hydrochloride, folic acid, calcium pantothenate, thiamine mononitrate, vitamin D_3 supplement) trace mineral premix (copper sulfate, manganese sulfate, ethylenediamine dihydriodide, sodium selenite), choline chloride, taurine, salt
B1: Natural Balance Zoo Carnivore Diet, Natural Balance Pet Foods, Inc. Burbank, CA	Beef, beef hearts, beet pulp, tricalcium phosphate, ground whole flaxseed, sodium chloride, choline chloride, taurine, vitamin E supplement, l-ascorbyl-2-polyphosphate (source of vitamin C), niacin, biotin, copper sulfate, vitamin A acetate, vitamin D_3 supplement, menadione dimethyl-pyrimidinol bisulfate, riboflavin, pyridoxine hydrochloride, thiamin mononitrate, manganese sulfate, d-calcium pantothenate, folic acid, ethylenediamine dihydriodide, calcium iodate, sodium selenite
B2: Nebraska-Brand: Special Beef Feline (Central Nebraska Packing Inc., North Platte, NE)	Beef, meat by-products, fish meal, soy bean meal, dried beet pulp, calcium carbonate, dicalcium phosphate, dried egg, brewers dried yeast, salt, vitamin premix (choline chloride, vitamin E supplement, niacin, vitamin B_{12} riboflavin, folic acid, vitamin A acetate, thiamine mononitrate, d-calcium pantothenate, mineral oil, biotin, pyridoxine hydrochloride, vitamin D_3 supplement), taurine, trace mineral premix (zinc oxide, manganous oxide, copper oxide, mineral oil, sodium selenite, calcium iodate)

ses. Apparent total tract digestibility values were calculated using the equation as follows:

[(nutrient intake– fecal nutrient output)/(nutrient intake)] × 100.

Digestible energy values were calculated using the following equation: (kcal/g gross energy in diet × energy digestibility coefficient of diet). Metabolizable energy of diets were estimated using modified Atwater values (8.5 kcal/g fat, 3.5 kcal/g protein, 3.5 kcal/g carbohydrate) multiplied by fat, protein, and digestible carbohydrate content of each diet. Digestible carbohydrate concentrations were calculated using nitrogen free extract (**NFE**) as an estimate with the following equation: [100 − (% ash + % CP + % fat + % TDF)]. Due to assay error (likely with the estimate of TDF) and expected low carbohydrate and high protein and fat concentrations of the diets, calculated NFE of some treatments produced negative numbers, in which case a value of 0 was used. ME also was calculated using the NRC equation published for felids: [ME = DE − (0.77 × g protein in diet)] (NRC, 2006).

Statistical Methods. All data were analyzed using the Mixed Models procedure of SAS (SAS Inst. Inc. Cary, NC). Data from all felids were averaged within diet because of low numbers for individual species. The fixed effects of diet and period were tested and felid was considered a random effect. Differences were determined using least squared means. A probability of $P < 0.05$ was considered statistically significant. Reported standard error of the means (SEM) were determined according to the Mixed Models procedure of SAS.

Experiment 2

A separate experiment was conducted to evaluate palatability using 6 exotic felids (3 male, 3 female) ranging in age from 7 to 20 yr and weight from 40 to 152 kg, including a cheetah (*Acinonyx jubatus*; $n = 1$), jaguars (*Panthera onca*; $n = 2$), puma (*Puma concolor;* $n = 1$), African lion (*Panthera leo*; $n = 1$) and Bengal tiger (*Panthera tigris tigris;* $n = 1$). None of the animals used in this study had previous exposure to raw pork products. A 2-bowl preference test (Griffin, 2003) was utilized with the zoo's normal carnivore diet (Nebraska-Brand: Special Beef Feline Diet) and the pork diet (Sustainable Swine Resources: Carnivore Essentials). Felids were offered 70% (by weight) of pork and beef diets for a total of 140% of baseline diet to ensure adequate intake if they only consumed 1 diet type offered. The study was conducted over 7 d, with the offering position (left or right) of each diet alternating daily. It is common practice in zoos to implement a "fasting day", during which the animals are not fed. This is believed to more closely mimic natural feeding patterns and aid in management practices (Altman et al., 2005). Fasting days were in place at this institution and were not removed for this experiment. The diet first-approached and first-tasted was recorded daily for each individual animal. Descriptive statistics only are presented for Exp. 2 because of small sample size.

RESULTS

Experiment 1

Diet Composition. Crude protein and fat concentrations ranged from 51.9 to 58.5% and 29.0 to 35.8%,

respectively. Total dietary fiber concentrations ranged from 5.5 to 7.9% and NFE concentrations ranged from 0 to 1.4%. Crude fiber concentrations were at least 56% less than TDF concentrations. The dietary treatments varied in ingredient composition but each diet evaluated contained raw meat as the first ingredient and predominately consisted of raw meats, by-products, fiber sources (beet pulp or cellulose) plus vitamin and minerals with the exception of B2 that also contained fish meal and soybean meal as additional sources of protein.

Energy and Macronutrient Digestibility. Treatment intakes, fecal outputs, and nutrient digestibility data are presented in Table 3. Dry matter and GE intakes were not different. Dry fecal output was 30% lower ($P < 0.05$) for Pork compared with Horse whereas wet fecal output was 32% lower ($P < 0.05$) for Horse compared with B2. Dry matter and CP digestibility values were greater ($P < 0.05$) for Pork compared with Horse and B2. Organic matter digestibility was 3.0% greater ($P < 0.05$) for Pork compared with Horse and fat digestibility was greater ($P < 0.05$) for Pork compared to either Beef treatment.

Calculated DE values for Pork, Horse, B1, and B2 diets were 5.8, 5.5, 5.5, and 5.8 kcal/g (dry matter basis [**DMB**]), respectively. Calculations using modified Atwater factors yielded ME predictions of 4.6, 4.5, 4.7, and 4.9 kcal/g (DMB), respectively, while the NRC equation predicted greater ME concentrations of 5.3, 5.0, 5.0, and 5.4 kcal/g for Pork, Horse, B1, and B2 diets, respectively (Table 3).

Table 3. Intake, fecal output, fecal characteristics, and apparent total tract macronutrient digestibility in captive large exotic felids ($n = 10$) fed raw meat diets

	Diet				
Item	Pork	Horse	B1[1]	B2[2]	SEM
Intake					
Food intake, g DM/d	570.0	612.3	546.5	596.0	128.4
GE intake, kcal/d	3,556.5	3,674.6	3,292.6	3,804.6	798.1
Fecal output					
Fecal output, g/d (as is)	264.9^{b,c}	232.1^{b}	301.3^{a,c}	343.1^{a}	76.8
Fecal output, g DM/d	69.0^{a}	98.6^{b}	79.1^{a,b}	87.3^{a,b}	20.3
Fecal scores	2.9^{b}	2.3^{c}	3.4^{a}	3.5^{a}	0.2
Apparent digestibility					
DM, %	88.0^{a}	83.6^{b}	86.1^{a,c}	85.6^{b,c}	1.1
OM, %	90.8^{a}	88.5^{b}	89.2^{a,b}	89.2^{a,b}	0.9
CP, %	95.7^{a}	92.7^{b}	95.2^{a}	93.1^{b}	1.0
Fat, %	98.5^{a}	99.0^{a}	95.4^{b}	96. 5^{b}	0.9
GE,[3] %	92.4^{a}	91.3^{a,b}	90.2^{b}	90.9^{a,b}	0.8
DE, kcal/g	5.8	5.5	5.5	5.8	—
ME, kcal/d,[4] kcal/g	4.6	4.5	4.7	4.9	—
ME, kcal/d,[5] kcal/g	5.3	5.0	5.0	5.4	—

$^{a–c}$Means within a row lacking a common superscript letter are different ($P < 0.05$).

[1]B1 = beef diet 1.

[2]B2 = beef diet 2.

[3]GE = gross energy.

[4]ME = 8.5 kcal ME/g fat + 3.5 kcal ME/g CP + 3.5 kcal ME/g N-free extract.

[5]ME = DE– (0.77 × g protein of diet).

Experiment 2

Observations of diet first-approached and first-tasted are presented in Table 4. Data were missing for the tiger on d 5 of the study due to keeper recording error. Of 32 total observations for first-approached, pork was selected by felids in 21 (65.6%) observations. Pork was selected by felids in 23 of 32 (71.9%) total observations for first-tasted.

DISCUSSION

Our objective was to determine if a pork-based diet was palatable and would support similar apparent total tract macronutrient digestibility and fecal scores, compared with standard zoological raw carnivore diets, formulated with either horse or beef, in large exotic felids. A variety of ages and species were used in this study, and though differences in digestibility may be present in animals of varying ages (Taylor et al., 1995; Teshima et al., 2010), separating effects of age and species was not an intention of this study. With regard to species, few differences in nutrient digestibility have been demonstrated between felid species (Vester et al., 2010a) and significant digestive differences between sexes have not been observed (Wynne, 1989; Vester et al., 2008). Although studies have evaluated various raw meat diets in large exotic felids, pork-based raw meat diets have not been investigated in these species.

Adding an additional dietary option to the zoological market is desirable for animal management. In domestic cats and dogs, novel protein sources may mitigate food allergies and sensitivities (Carlotti et al., 1990; Guilford et al., 2001) as well as colitis and irritable bowel syndrome (**IBS**; Simpson, 1998; Verlinden et al., 2006). There is merit in evaluating the effects of novel protein sources for health improvements in exotic felids and this warrants further research efforts.

Additionally, novel protein sources provide dietary variety. Authors are not aware of published research testing effects of providing dietary variety to captive exotic felids on health improvements; however, documented natural history of these species indicates they are exposed to vast prey variety in the wild. Large exotic felid species, such as tigers, lions, leopards, and cheetahs, may opportunistically feed on up to 30 different prey types in the wild (Lindburg, 1988). Therefore, providing dietary variety more closely mimics natural dietary habits and serves as a source of enrichment for captive managed animals.

Table 4. Number of large exotic felids (*Panthera tigris tigris* [*n* = 1], *Puma concolor* [*n* = 1], *Panthera leo* [*n* = 1], *Acinonyx jubatus* [*n* = 1], *Panthera onca* [*n* = 2]) that first approached and first tasted a beef- and pork-based raw meat diet when diets were simultaneously presented in a two-bowl preference test for 7 d

	First approached				First tasted			
	Beef	Pork	Fasting[1]	Missing[2]	Beef	Pork	Fasting[1]	Missing[2]
Day 1	3	3	0	0	3	3	0	0
Day 2	0	6	0	0	0	6	0	0
Day 3	1	1	4	0	0	2	4	0
Day 4	3	3	0	0	2	4	0	0
Day 5	3	2	0	1	3	2	0	1
Day 6	1	5	0	0	1	5	0	0
Day 7	0	1	5	0	0	1	5	0
Total	11	21	9	1	9	23	9	1

[1]Fasting days were days when felids were not offered raw meat diets.

[2]One day of data collection for 1 animal was missing due to keeper recording error.

Diet Composition

As expected, CP and fat concentrations were similar to CP and fat concentrations of raw meat diets reported in previous studies (44.9 to 64.5% and 22.2 to 36.9%, respectively; Crissey et al., 1997; Vester et al., 2008; Vester et al., 2010a; Kerr et al., 2013). In those that reported it (Vester et al., 2008; Kerr et al., 2013), TDF in previous studies (4.8 to 8.4%) was similar to those determined in the current study. Compared with TDF, CF concentrations were approximately 56% lower (2.3 to 3.5%), indicating poor recovery of relevant dietary fibers within the CF assay. While TDF may not recover some animal fiber components, it may be the more optimal assay to date for consideration of fiber in raw meat and whole prey diets for zoo managed animals. All diet macronutrient compositions fell within ranges reported for domestic felid requirements (NRC, 2006).

Macronutrient and Energy Digestibility

Macronutrient digestibility values ranged from 83.6 to 99.0% indicating nutrient availability from the raw meat diets. Previous studies reported similar ranges of DM (80.9 to 89.1%), OM (86.7 to 96.4%), CP (91.0 to 96.9%), and GE (88.9 to 95.2%) digestibility in large exotic felids fed beef or horse-based raw meat diets. Fat digestibility values reported in the previous studies (90.5 to 96.2%) were slightly lower than those in the current study (95.4 to 99.0%; Vester et al., 2008; Vester et al., 2010a; Kerr et al., 2013); however, those studies used acid hydrolysis for fat analysis whereas Soxhlet methodology was utilized in the present study and likely explains the documented differences. Typically, acid hydrolysis yields greater fat recovery in meats with more pronounced differences at lower fat concentrations or with cooked meats (Habeck et al., 2013). Due to high fat concentrations of the raw meat diets in the present study, conducting a digestibility experiment directly comparing the 2 analytical methodologies for fat within these types of diets, may be warranted.

Wild exotic felids obtain up to 60% of their total energy from dietary fat (Scott, 1968). Although all diets in the present study had high fat digestibility values, the statistically greater digestibility of fat detected when felids consumed Pork or Horse compared to beef diets may have resulted from variations in fatty acid profiles of the different sources. According to He et al. (2005), horsemeat may contain 76% more PUFA, 12% less MUFA, and nearly 20% less saturated fatty acids compared to beef or pork. Additionally, horse lipids also contain 2 and 5 times more linoleic acid (C18:2) and 8 and 18 times more linolenic acid (C18:3), respectively compared to beef and pork. In general, beef is greater in medium chain fatty acids (C8 to C13) and pork is lower in long chain fatty acids (Irina, 2011). Although 1 study, conducted by Kane et al. (1981) did not demonstrate differences in digestibility values of individual fatty acids fed to domestic felids, this area warrants further investigation as the specifics of fat digestion for various types of fats (saturated, unsaturated, etc.) in felids are not well understood and could provide explanation of variations in fat digestibility and possibly dietary preferences.

All tested diets had high protein digestibility values (92.7 to 95.7%). Ingredients likely contributed to protein digestibility differences. In addition to beef and meat by-products, the B2 diet also contained fish meal and soybean meal as protein sources. The other dietary treatments contained no rendered meals or plant protein feedstuffs and only consisted of muscle meats and raw meat by-products as protein sources. Plant protein sources such as soybean meal are less digestible than animal protein sources for carnivores, likely due to higher concentrations of carbohydrates (McDonald, 2002). Soybean meal contains 22 to 25% neutral detergent fiber (Karr-Lilienthal et al., 2004) that will not efficiently be digested by felids. These factors may have contributed to reduced protein digestibility observed with the beef diet containing soybean meal and fish meal. Statistically lower protein digestibility in felids fed Horse and B2 also was likely a result of reduced protein concentrations of those particular diets (Badiani et al., 1997).

Using composition and energy digestibility coefficients, the DE concentrations were 5.8, 5.5, 5.5, and 5.8 kcal/g, respectively for Pork, Horse, B1, and B2. Common methods of predicting metabolizable energy (ME) values for domestic felid diets include calculations using modified Atwater factors (8.5 kcal/g

fat, 3.5 kcal/g protein, 3.5 kcal/g NFE) or the NRC equation [ME = DE – (0.77 × g protein)] (NRC, 2006). Calculations for ME using modified Atwater factors and the NRC equation predicted 4.6, 4.5, 4.7, and 4.9 and 5.3, 5.0, 5.0, and 5.4 kcal/g ME for Pork, Horse, B1, and B2, respectively. Atwater factors are derived from energy content of nutrients as well as digestibility of a standard diet. Specifically, modified Atwater factors reflect digestibility values of standard kibble diets of 85.0, 95.0, and 80.0% for carbohydrate, fat, and protein, respectively (Kienzle, 2002). Results from the current study indicate fat digestibility up to 99.0% and protein digestibility up to 95.7%. Greater digestibility of raw meat diets shown in this study, and supported by those previously discussed, leads to an underestimation of ME when modified Atwater factors are applied. This is due to differences in digestibility of processed petfoods such as extruded kibbles compared with raw diets (Björck et al., 1983; Björck et al., 1984, Camire et al., 1990; Crissey et al., 1997; Vester et al., 2010b; Kerr et al., 2012); therefore, modified Atwater factors are likely not appropriate for estimating ME of raw meat diets. Differences between the DE and ME of the diets used in the current study were as high as 20.8% using modified Atwater factors and 8.2% using the NRC equation. Urine energy losses in domestic felids were 6.5% of energy intake when fed a high protein (61.5%) canned diet (mixed with beef heart) and 4.6% in felids fed a high fat diet (49.1% fat, 39.9% protein; Riond et al., 2003). Urine energy losses have not been evaluated in felids fed high protein, high fat raw meat diets but it would be hypothesized the losses would be within the range previously reported by Riond et al. (2003). Gaseous energy losses in felids fed raw meat diets would be negligible because of limited fermentation in the large bowel and very low fiber concentrations in diets; therefore, differences between DE and ME are likely lower for raw meat diets than current prediction methods project. Until further data can determine if there are substantial differences in urine energy losses, the predictive equation from the NRC is likely more appropriate than modified Atwater factors for predicting ME of raw meat diets.

Fecal scores

Fiber sources included cellulose in Horse, beet pulp in B1 and B2 diets, and both beet pulp and cellulose in the Pork diet. Smaller felid species, such as cheetahs, were reported to tolerate beet pulp as a source of fiber while larger species, such as tigers, required cellulose to limit fermentation and maintain optimal fecal scores (Kerr, 2012). Cellulose, a non-fermentable fiber, provides the bowel with tactile stimulation, inducing colonic motility (Bueno et al., 2000b), while fermentable fibers, such as beet pulp, induce production of short chain fatty acids (**SCFA**), that can be absorbed for energy (Bueno et al., 2000a). Too much fermentable fiber in the diet may result in excess production of SCFA, increasing passive transport absorption and possibly resulting in wetter stool (higher fecal score) compared to that of an animal receiving a less fermentable fiber source. This is reflected in the current study where fecal scores from felids fed B1 and B2 diets, containing beet pulp as a fiber source, were higher (looser; $P < 0.05$) than scores from felids fed Horse or Pork. Additionally, fecal scores from felids fed Horse, that contained only cellulose as the fiber source, had the lowest values (harder; $P < 0.05$). It has been suggested that a complete raw diet should include a combination of 2% beet pulp and 2% cellulose (maximum) to achieve optimal intestinal health (Kerr, 2012) and this hypothesis is supported in the current study because the Pork diet, which contained both beet pulp and cellulose in equal proportions, had fecal scores closest to ideal (3.0). However, differences among carnivore species are not well documented and further research determining optimal fermentable to non-fermentable dietary fiber ratios is warranted.

Through grooming, felids may ingest large amounts of fur, which is then excreted and is visible in feces. Hair in fecal material would be analyzed primarily as protein because it is composed of up to 95% protein, primarily keratin, with the rest being water and lipid (Robbins, 2012). Because ingestion of hair cannot be controlled or accurately quantified in feces in zoo-based research, protein digestibility values may be inaccurate. Undigested protein analyzed in feces (excreted) would reduce the apparent protein digestibility, meaning protein digestibility may have actually been greater than reported. Recently, the concept of animal fiber has received more attention. Ingested hair and fur that is undigested acts essentially as a type of fiber that can be categorized as animal fiber. Typical fiber assays (crude and total dietary fiber) capture plant-based fibers and were not developed to account for animal-based components that act as dietary fiber. Whole prey consumption reduced fecal phenol and indole production by 65.5 and 61.4%, respectively, in cheetahs fed whole rabbits versus a ground raw meat diet (Depauw et al., 2013). This reduction was attributed in part to animal fiber. Lower concentrations of phenols and indoles may improve gut health because presence of those compounds reduces the viability of beneficial intestinal bacteria (Nowak and Libudzisz, 2006). An assay specific for animal fiber might more accurately reflect the fiber present in raw carnivore diets and should be researched further.

Our objective was to determine the utilization of a new pork-based commercial diet for zoo-managed

felids in comparison to 3 other commonly fed diets. Diets evaluated in this study were not standardized for ingredients, and represent actual diets commonly fed to zoo carnivores. As expected, dietary treatments varied in ingredients and composition; therefore, differences in observed macronutrient digestibility cannot be attributed strictly to any single protein or ingredient source. However, based on digestibility results and fecal scores, a raw 100% pork-based diet can be utilized effectively by exotic felids managed in zoos.

A period effect was detected during statistical evaluation regarding, DM ($P = 0.0012$), OM ($P = 0.0064$), and GE ($P = 0.0075$) digestibility values. The reason for this is not clear, but temperature and rainfall were ruled out because of similarity between periods. Visitor presence was higher during late May to early June and could have affected digestibility in that period. It is possible that felids were affected by increased zoo attendance; therefore research in this area is warranted.

Palatability

Large exotic felids offered pork selected it more than 50% of the time. This information is valuable because many felids refuse to eat certain diets, for various reasons. The objective of this experiment was not to determine a preference between beef and pork, but rather to determine if felids would consume the pork diet (i.e.,- if it was palatable). Dietary variety without palatability is counterproductive and may lead to diet refusals and possibly nutritional inadequacies. From this perspective, palatability is equally as important as nutritional adequacy and digestibility. Likewise, it is essential to recognize that felids having little exposure to varied diets may not necessarily consume a new option. This should be considered during initial palatability evaluation or attempts for diet introduction because a single offering is not likely representative of felid acceptance long-term. The felids in the present study were routinely offered a variety of meats and whole prey before the start of the study; therefore, they may have accepted the pork diet more readily than counterparts managed at institutions providing little to no dietary variety.

Conclusions

Although some macronutrient and energy digestibility values, as well as fecal scores, differed statistically, all diets were well digested by study subjects. Raw pork-based diets have not been evaluated for digestibility in exotic felids before this study. Numerically, Pork was the most digestible for every macronutrient analyzed, with exception of fat. Additionally, on average, felids consuming the Pork diet had fecal scores that were closest to ideal (considered 3.0). Further research is needed to elucidate specific nutrient concentrations and ingredients that may be considered ideal for various managed exotic felid species and perhaps further application of pork for other carnivores including birds of prey, canids, and bears. In conclusion, our data suggest that exotic managed felids consume and utilize raw pork and pork by-products as a dietary option.

LITERATURE CITED

Altman, J. D., K. L. Gross, and S. R. Lowry. 2005. Nutritional and behavioral effects of gorge and fast feeding in captive lions. J. Appl. Anim. Welf. Sci. 8:47–57.

AOAC. 2000. Fat (crude) or ether extract in meat. Method 960.39: Official Methods of Analysis. Chapter 39. The Association of Official Analytical Chemists International, Gaithersburg, MD. p. 2.

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

Badiani, A., N. Nanni, P. P. Gatta, B. Tolomelli, and M. Manfredini. 1997. Nutrient profile of horsemeat. J. Food Compost. Anal. 10:254–269. doi:10.1006/jfca.1997.0540

Björck, I., N. G. Asp, and A. Dahlqvist. 1984. Protein nutritional value of extrusion-cooked wheat flours. Food Chem. 15:203–214. doi:10.1016/0308-8146(84)90004-9

Björck, I., A. Noguchi, N. G. Asp, J. C. Cheftel, and A. Dahlqvist. 1983. Protein nutritional value of a biscuit processed by extrusion cooking: Effects on available lysine. J. Agr. Food Chem. 31:488–492. doi:10.1021/jf00117a006

Bradshaw, J. W. S. 2006. The evolutionary basis for the feeding behavior of domestic dogs (*Canis familiaris*) and cats (*Felis catus*). J. Nutr. 136:1927S–1931S.

Bueno, A. R., T. G. Cappel, G. D. Sunvold, R. A. Moxley, G. A. Reinhart, and E. T. Clemens. 2000a. Feline colonic microbes and fatty acid transport: Effects of feeding cellulose, beet pulp and pectin/gum arabic fibers. Nutr. Res. 20:1319–1328. doi:10.1016/S0271-5317(00)00211-6

Bueno, A. R., T. G. Cappel, G. D. Sunvold, G. A. Reinhart, and E. T. Clemens. 2000b. Feline colonic morphology and mucosal tissue energetics as influenced via the source of dietary fiber. Nutr. Res. 20:985–993. doi:10.1016/S0271-5317(00)00189-5

Camire, M. E., A. Camire, and K. Krumhar. 1990. Chemical and nutritional changes in foods during extrusion. Crit. Rev. Food Sci. 29:35–57. doi:10.1080/10408399009527513

Carlotti, D. N., I. Remy, and C. Prost. 1990. Food allergy in dogs and cats. A review and report of 43 cases. Vet. Dermatol. 1:55–62. doi:10.1111/j.1365-3164.1990.tb00080.x

Crissey, S. D., J. A. Swanson, B. A. Lintzenich, B. A. Brewer, and K. A. Slifka. 1997. Use of a raw meat-based diet or a dry kibble diet for sand cats (*Felis margarita*). J. Anim. Sci. 75:2154–2160.

Depauw, S., M. Hesta, K. Whitehouse-Tedd, L. Vanhaecke, A. Verbrugghe, and G. P. J. Janssens. 2013. Animal fibre: The forgotten nutrient in strict carnivores? First insights in the cheetah. J. Anim. Physiol. Anim. Nutr. 97:146–154.

Felid Taxon Advisory Group. 2014. Basic fecal scale—Felids. Felid Taxon Advisory Group, AZA, Silver Spring, MD.

Griffin, R. W. 2003. Palatability testing methods: Parameters and analyses that influence test conditions. In: J. L. Kvamme and T. D. Phillips, editors, Petfood Technology. Watt, Mt. Morris, IL. p. 187–193.

Guilford, W. G., B. R. Jones, P. J. Markwell, D. G. Arthur, M. G. Collett, and J. G. Harte. 2001. Food sensitivity in cats with chronic idiopathic gastrointestinal problems. J. Vet. Intern. Med. 15:7–13. doi:10.1111/j.1939-1676.2001.tb02291.x

Habeck, S., B. Mitchell, and D. Sullivan. 2013. Comparison of fat extraction methods for analysis of meat. In: Proc. AOAC 127th Annu. Meet. Expo., Chicago, IL.

He, M. L., S. Ishikawa, and H. Hidari. 2005. Fatty acid profiles of various muscles and adipose tissues from fattening horses in comparison with beef cattle and pigs. Asian Australas. J. Anim. 18:1655. doi:10.5713/ajas.2005.1655

Irina, C. 2011. Comparative study of meat composition from various animal species. Tehnologija mesa 52:167–171.

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.

Karr-Lilienthal, L. K., C. M. Grieshop, N. R. Merchen, D. C. Mahan, and G. C. Fahey. 2004. Chemical composition and protein quality comparisons of soybeans and soybean meals from five leading soybean-producing countries. J. Agric. Food Chem. 52:6193–6199. doi:10.1021/jf049795+

Kerr, K. 2012. Nutritional evaluation of raw meat and whole prey diets for domestic and exotic cats. PhD Diss. University of Illinois, Urbana-Champaign.

Kerr, K. R., A. N. Beloshapka, C. L. Morris, C. M. Parsons, S. L. Burke, P. L. Utterback, and K. S. Swanson. 2013. Evaluation of four raw meat diets using domestic cats, captive exotic felids, and cecectomized roosters. J. Anim. Sci. 91:225–237. doi:10.2527/jas.2011-4835

Kerr, K. R., B. M. Vester Boler, 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. doi:10.2527/jas.2010-3266

Kienzle, E. 2002. Further developments in the prediction of metabolizable energy (ME) in pet food. J. Nutr. 132:1796S–1798S.

Lindburg, D. G. 1988. Improving the feeding of captive felines through application of field data. Zoo Biol. 7:211–218. doi:10.1002/zoo.1430070303

McDonald, P. 2002. Digestion in the dog and cat: Digestion. In: R. A. Edwards, J. F. D. Greenhalgh, C. A. Morgan, L. A. Sinclair, R. G. Wilkinson, editors, Animal nutrition. Pearson Education, Harlow, UK, p. 166–190.

Nowak, A., and Z. Libudzisz. 2006. Influence of phenol, p-cresol and indole on growth and survival of intestinal lactic acid bacteria. Anaerobe 12:80–84. doi:10.1016/j.anaerobe.2005.10.003

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

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

Riond, J. L., M. Stiefel, C. Wenk, and M. Wanner. 2003. Nutrition studies on protein and energy in domestic cats. J. Anim. Physiol. Anim. Nutr. 87:221–228.

Robbins, C. 2012. Chemical composition of different hair yypes, chemical and physical behavior of human hair. Springer Berlin Heidelberg. p. 105–176. doi:10.1007/978-3-642-25611-0_2

Scott, P. P. 1968. The special features of nutrition of cats, with observations on wild felidae nutrition in the London Zoo. Symp. Zool. Soc. London 21:21–36.

Simpson, J. W. 1998. Diet and large intestinal disease in dogs and cats. J. Nutr. 128:2717S–2722S.

Taylor, E. J., Adams, C. and Neville, R. 1995. Some nutritional aspects of ageing in dogs and cats. Proc. Nutr. Soc. 54:645–656. doi:10.1079/PNS19950064

Teshima, E., M. A. Brunetto, R. S. Vasconcellos, K. N. V. Gonçalves, L. D. De-Oliveira, A. G. Valério, and A. C. Carciofi. 2010. Nutrient digestibility, but not mineral absorption, is age-dependent in cats. J. Anim. Physiol. Anim. Nutri. 94:e251–e258.

Thiex, N. 2008. Evaluation of analytical methods for the determination of moisture, crude protein, crude fat, and crude fiber in distillers dried grains with solubles. J. AOAC Int. 92:61–73.

Verlinden, A., M. Hesta, S. Millet, and G. P. J. Janssens. 2006. Food allergy in dogs and cats: A review. Crit. Rev. Food Sci. 46:259–273. doi:10.1080/10408390591001117

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. doi:10.1002/zoo.20172

Vester, B. M., S. L. Burke, K. J. Liu, C. L. Dikeman, L. G. Simmons, and K. S. Swanson. 2010b. Influence of feeding raw or extruded feline diets on nutrient digestibility and nitrogen metabolism of African wildcats (*Felis lybica*). Zoo Biol. 29:676–686. doi:10.1002/zoo.20305

Wynne, J. E. 1989. Comparative digestibility values in four species of felidae. J. Zoo Wildl. Med. 20:53–56.