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Utilization of pork and pork by-products for nutritional and behavioral management of captive exotic felids

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Utilization of pork and pork by-products for nutritional and behavioral management of captive exotic felids

by

Cayla Jo Iske

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Animal Science

Program of Study Committee:
Cheryl L. Morris, Major Professor
Anna K. Johnson
Elisabeth J. Lonergan
Howard D. Tyler

Iowa State University
Ames, Iowa
2015

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ABSTRACT

Currently two protein sources (beef or horse) comprise the majority of raw meat diet formulations for exotic carnivores in zoological institutions. Pork-based diets have traditionally not been fed to managed exotic carnivores, primarily because of microbial and pathogenic concerns, and nutrient digestibility of pork has not been evaluated in captive exotic carnivores, such as felids. Additionally, commercially prepared raw meat diets, while nutritionally complete, rarely meet nonnutritive requirements of cats, such as locating, capturing, and killing prey as well as psychological aspects related to the feeding process, and oral health needs. The pork industry currently sends many by-products to rendering that have the potential to be used in raw carnivore diets or as environmental enrichment.

The overall objectives of this research were to evaluate a raw, pork-based diet for small and large captive exotic felids, including diet compositional analyses, fecal scores, palatability, and microbial loads. Additionally, the use of pork by-products as environmental enrichment devices for large captive exotic felids was evaluated. Our first aim was to determine apparent total tract macronutrient digestibility, fecal scores, and palatability of a pork-based diet compared with standard zoological carnivore diets formulated with either horse or beef, in large captive exotic felids. Our second aim was to determine if a pork-based diet had similar apparent total tract macronutrient digestibility and fecal scores as standard zoological carnivore diets formulated with either horse or beef, in small exotic felids, and evaluate microbial populations in raw diets. Our third aim was to evaluate 11 pork by-products for macronutrient and mineral composition and determine if a pig head would be a
biologically relevant environmental enrichment device for large felids kept in a zoological setting.

In general, a raw pork-based diet was well digested and utilized by large and small captive exotic felids. All raw meat diets used in these studies were highly digestible, and the pork-based diet was similarly or more digested compared to other protein sources. Fecal scores were healthy when felids were fed the pork-based diet and the diet was determined palatable for the tested cats. The use of raw pork by-products also provides opportunity as potential environmental enrichment.

In our first aim, we demonstrated that a raw pork-based diet was highly digestible in large exotic felids by using four raw meat dietary treatments: one horse-based (Horse), two beef-based (B1, B2), and one pork-based diet (Pork). Dry matter (DM) and crude protein (CP) apparent digestibilities were higher (P<0.05) in cats fed Pork (87.97 and 95.74%) compared with cats fed Horse (83.59 and 92.71%) and B2 (85.60 and 93.14%). Apparent organic matter (OM) digestibility was higher (P<0.05) in cats fed Pork (90.76%) than cats fed Horse (88.53%). Apparent fat digestibility values were high across all treatments but were higher (P<0.05) in cats fed Pork (98.51%) compared with cats fed B1 (95.51%) or B2 (96.45%). Gross energy (GE) digestibility values were higher in cats fed Pork (92.38%) compared with B1 (90.21%). Using a scale of 1 to 5, with 3 considered ideal, average fecal scores were 2.30, 2.94, 3.42, and 3.54 for Horse, Pork, B1 and B2, respectively; and were different between every treatment with the exception of B1 and B2 which were not statistically different. The pork-based diet was palatable and was selected in 24 of 37 total (64.86%) observations of first approached and 23 out of 33 total (69.70%) observations for first tasted, compared to a raw beef-based diet.
In our second aim, we showed that a raw pork-based diet was highly digestible in small exotic felids by using raw horse (Horse), beef (Beef), beef/horse blend (Blend), and pork-based (Pork) dietary treatments. All diets were highly digestible, especially fat digestibility (98.58 to 99.73%) in which there were no statistical differences between diets. Digestibility of OM was higher (P<0.05) when cats consumed the Blend diet (97.15%) compared to the Pork diet (93.10%). Fecal scores ranged from 1.55 to 2.63, with Beef (2.63) being statistically higher (P<0.05) than Horse (1.55) and Pork (1.91). Additionally, microbial counts were shown to be highly variable in dietary treatments (E. Coli: 110 to 10,000 cfu/g; total coliforms: 150 to 28,000 cfu/g; yeast: 20 to 4,000 cfu/g; mold count: not detectable to 10 cfu/g; aerobic plate count: 23,000 to 26,000,000 cfu/g). Staphylococcus aureus was not detected in any of the diets. *Salmonella* was presumptive positive in the Pork and Blend diet, and was negative in the other three diets, but no signs of clinical illness were observed in cats fed any of the evaluated diets.

In our third aim, it was demonstrated that pork by-products ranged widely in composition and have potential for use as biologically relevant environmental enrichment for captive exotic felids. Ranges of macronutrient composition for 11 pork by-products were: DM: 26.01-71.23%; OM: 53.04-96.79%; CP: 22.90-79.29%; fat: 22.01-63.15%; CF: 0.25-19.54%; total dietary fiber (TDF): 0.04-3.44%; GE: 3.73-7.45 kcal/g. Potential use of these by-products as environmental enrichment was demonstrated by offering five large exotic felids a pig head, and observing their behavior on Baseline (before head offered), Enrichment (head offered), and Post enrichment (head removed) days, over 4 weeks, using instantaneous scan sampling at one minute intervals for 2 hours in the morning. Active behaviors were observed to be 55.70% higher (P<0.0001) on Enrichment days compared to Baseline and
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approach the head (seconds) and loss in head weight from before to after offering to the cat (grams) were not statistically different (P>0.05) across weeks.

Dietary variety is important for exotic felid health as well as managerial flexibility. Enrichment also has been an area of increasing interest for zoos over the past several
decades. This research has demonstrated that a pork-based raw meat diet can be included
among dietary options for captive exotic felids and that, while microbial populations in these
diets are high, felids can tolerate microbial load present in raw meat diets. Additionally, pork
by-products can provide valuable nutrients while fulfilling nonnutritive needs of exotic felids that are not provided by commercially prepared soft, raw meat diets.
CHAPTER 1
INTRODUCTION

In zoological institutions, carnivores are typically fed raw meat diets containing beef or horsemeat as protein sources. Although research addressing health benefits of raw meat diets in felids are lacking, studies have shown these diets are highly digestible when fed to managed exotic felids and domestic cats (Kendall et al., 1982; Crissey et al., 1997; Vester et al., 2008; Vester et al., 2010; Kerr et al., 2013). A raw pork-based diet has previously not been evaluated and is currently not commonly fed in zoological institutions. Reluctance to feed pork diets may be due to specific pathogenic concerns associated with pork including *Trichinella* (Greve, 2012), pseudorabies (Aujeszyk’s disease) (Mettenleiter et al., 2012), and *Toxoplasma* (Lindsay et al., 2012). Additionally, *Salmonella* and *Escherichia coli* (E. coli), are of concern when feeding any raw meat diet. Proper storage and handling (Crissey et al., 2001) as well as improved farming practices such as not feeding garbage (Greve, 2012; Lindsay et al., 2012) and microbial interventions used by producers, such as high pressure pasteurization (Rastogi et al., 2007), irradiation (Farkas, 1998), and organic acids (Ricke, 2003) have all helped mitigate these issues in the past few decades.

Cats may develop aversions to foods comprising the majority of their diets for an extended period of time, known as the monotony effect (Bradshaw, 2006). Cats also may develop an aversion to foods they have not consumed before, especially if they have been fed one type of diet for much of their life, known as neophobia (Bradshaw, 2006). Neophobia can cause issues with management because a change in diet may result in an animal ceasing
to eat. For this reason, adding variety to felid diets is desirable but it is important to evaluate the palatability of new dietary options for managed felids.

During commercial manufacture of human grade pork products, such as sausage, up to 40% of live pig weight is discarded to rendering facilities (SSR, 2014) and typical dressing percentage for the swine industry is approximately 70% (SDSU, 2015), leaving around 30% to be discarded. Nutritionally rich by-products including liver, spleen, tongue, and bones may be among the items discarded to the rendering process. Since 1927, more than 70% of rendering facilities have closed (Bisplinghoff, 2006; Meeker, 2009), mainly because of heightened regulations from the Environmental Protection Agency (Morrow and Ferket, 2001), causing costs associated with rendering to rise. This has led pork producers to look for other avenues to add value to their products. Utilizing by-products, typically sent to rendering, in a raw meat diet adds variety for carnivores managed in zoos while adding value to by-products for pork producers.

Additionally, there are no published regulations for allowable microbial loads in raw carnivore diets. The ability of cats to remain asymptomatic after consuming raw meat contaminated with *Salmonella* (Finley et al., 2006), however, suggests they can tolerate high numbers of microorganisms in their food, compared to humans. It may be desirable to set recommendations on allowable microbial loads in raw meat diets fed to felids, but acceptable and reasonable levels for these animals has not been adequately investigated or determined.

Processed, soft raw meat diets typically fed in North American zoos are formulated to meet nutritional requirements, but these diets lack the physical properties of wild exotic felid diets. Lack of mastication for consumption may contribute to behavioral and health problems (Fitch and Fagan, 1982). Zoos have been very active in considering different environmental
enrichment strategies to encourage species-specific behaviors that are beneficial to the animal (Carlstead and Shepherdson, 2000). Environmental enrichment can be classified into five areas: social, occupational, physical, and sensory and nutrition (FASS, 2010). Pork by-products such as pig-heads and various bones have the potential to be environmental enrichment items, and may satisfy occupational, sensory, and nutritional enrichment.

Offering novel objects can provide environmental enrichment to mitigate behavioral concerns and health problems in captive animals (Tripp, 1985; Young, 2003).

Our overall objectives were to evaluate the use of pork and pork by-products in diets and environmental enrichment used for captive exotic felids.

Our first aim was to evaluate the influence of pork and pork by-products on macronutrient digestibility, fecal scores, and palatability, compared to standard zoological carnivore diets (beef or horse-based), in large captive exotic felids. Four dietary treatments were analyzed for chemical composition and fed to large exotic felids. Apparent total tract macronutrient digestibility and fecal scores were evaluated in ten individuals, including five different species. Additionally, palatability was assessed using a two-bowl preference test, comparing a beef-based and pork-based diet.

The second aim of our research was to evaluate the influence of pork and pork by-products on macronutrient digestibility and fecal scores, compared to standard zoological carnivore diets (beef or horse-based), in small captive exotic felids, as well as evaluate microbial populations in commercially available raw meat diets. Four dietary treatments were analyzed for chemical composition, digestibility, and microbial population levels.

Our third aim was to evaluate pork-based by-products for macronutrient and mineral composition and to determine if a pig head provided biologically relevant environmental
enrichment for captive large exotic felids. Eleven pork by-products were analyzed including: heads, snouts, femurs, humerus, scapulas, ribs, necks, feet, tails, lower jaws, and ear canals.

Pig heads were used in a behavioral study to evaluate the use of pork by-products as environmental enrichment devices for captive large exotic felids. Five large exotic felids were observed using instantaneous scan sampling at one min intervals, with behaviors being tracked from a preset ethogram, on Baseline, Enrichment, and Post enrichment days, over 4 consecutive weeks. Number of location changes, ors, fecal scores, time to approach enrichment, and loss in head weight were also recorded.

Literature Cited


SDSU, 2015, Swine Grading, Brookings, SD, South Dakota State University.

SSR, 2014, Unpublished, Sustainable Swine Resources, LLC.


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 Biology, v. 27, p. 126-36.


CHAPTER 2
LITERATURE REVIEW

Pork Industry

In 1927 it was estimated that 913 rendering facilities were in operation in the United States; by 1975 that number had dropped to 724 and by 2006 it had further declined to 273 (Bisplinghoff, 2006). In 2009, 250 rendering plants in North America were documented (Meeker, 2009). A variety of causal factors have resulted in the decline of rendering facilities, including increased regulation on emissions and air pollutants (EPA, 1995) by the Environmental Protection Agency (Morrow and Ferket, 2001). With fewer rendering facilities, costs associated with processing meat by-products have increased due to increased transportation distances. This quandrum has challenged the U.S. pork industry to explore new and more cost effective ways to improve the value of harvested animals, particularly for by-product meat components.

Today, approximately 40% of live pig weight is discarded to rendering facilities (SSR, 2014) and the average range for dressing percent for the swine industry is 68-77% (SDSU, 2015). Tongue, liver, spleen, and several other organ meats, often called variety meats, are among by-products typically sent to rendering facilities or marketed to niche consumers. Swine producers have expressed interest in increasing pig value through value added by-products for many years (Buhr, 2004; NPB, 1999) and continue to look for different avenues to do so. This may be accomplished through the production of a commercial raw meat diet for carnivores that utilizes pork by-products as a majority of the formulation, without need for further processing. Not only would this add value to pork by-products for producers, it could provide an additional high quality dietary option for
carnivores in managed environments including zoos. Some of these by-products may provide exceptional nutritional quality. Beef tongue and chicken liver can contain concentrations of taurine (an essential amino acid for cats) up to 1,752 and 1,100 mg/kg (as-fed), respectively (Spitze et al., 2003). Other organ meats such as beef kidney contain concentrations of approximately 36 mg/kg of riboflavin, while lamb liver contains 0.02% magnesium and high concentrations of vitamin A (314 μg/g), all on an as-fed basis (Williams, 2007). Beef spleen is considered a good source of dietary iron (750 mg/kg as fed) and pig liver has a large concentration of vitamin A (151 IU/g) (Kizlaitis et al., 1962). These concentrations are adequate to provide nutrients that meet cat requirements. For example, if a tiger is consuming 5.5 kg (1.6 kg dry matter) of a raw meat diet that contains 5,500 kcal/kg, less than 8 grams of lamb liver would be required in the diet to meet the vitamin A requirement (NRC, 2006). In addition, many of the large bones (femur, humerus, heads) may include high concentrations of calcium and phosphorus and many anatomical regions of the pig are high in cartilage (ear canals, snouts) and in turn may have potential to be used as enrichment items for animals in managed environments.

Carnivorous Characteristics That Drive Nutrition

The order Carnivora is composed of seven families: Canidae (dogs), Ursidae (bears), Procyonidae (raccoons, pandas, etc.), Mustelidae (badgers, skunks, otters, etc.), Viverridae (mongooses, civets, etc.), Hyaenidae (hyaenas), and Felidae (cats) (Ewer, 1998). Contrary to the name, being carnivorous is not an absolute requirement of animals in the Carnivora order. Carnivora species show a wide range of feeding behaviors and characteristics. Some species belonging to this order are strict carnivores, such as seals and cats, but others consume herbivorous diets, such as pandas. Some Carnivora are specialists (a large part of
their diet is made up of one prey/food), for instance the Ethiopian wolf’s (*Canis simensis*)
diet is more than 90% rodents, while others are generalists (their diet is comprised of several
different prey/food types). A wide range of anatomical characteristics, such as body size (80
g weasel to 800,000 g polar bear), are also seen in this order. Additionally, *Carnivora*
members inhabit every habitat from ocean waters (sea otter) to tropical forest (kinkajou) to
desert (fennec fox). The only truly defining characteristic of all species in the order is the
presence of sharp carnassial teeth used for ripping, sawing, and cutting food (Nowak, 2005)
and shorter digestive tracts than other non-herbivores.

**Felids**

Felids are highly specialized carnivores, indicated not only by their idiosyncratic
nutritional requirements but also their physical characteristics such as dentition (dominant
canines and carnassial teeth for killing prey), retractable claws and unique senses of taste
specific for meat (do not taste salty or sweet but are sensitive to specific amino acids).
Domestic cats and small exotic felids are solitary hunters resulting in several kills of small,
opportunistic prey daily (Bradshaw, 2006) while large wild exotic felids, such as tigers, may
make one large kill on which they feed for several days (Lindburg, 1988). In the wild,
hunting and consumption of a wide variety of prey ensures that nutritional requirements are
met daily even if, at any single meal, prey is nutritionally unbalanced or deficient in key
nutrients. Compared to domestic dogs, cats are more specialized predators largely because
dogs were domesticated from wolves (*Canis lupus*) beginning approximately 14,000 years
ago (Bradshaw, 2006) while cats were domesticated from African wildcats (*Felis silvestris*
lybica) much more recently, only in the past 4,000 years (Serpell, 2000). Thus, there are
many discrepancies between domestic dogs and their wild ancestors, such as docility,
appearance, and hunting style. Discrepancies can also be seen genetically, with 3.8 million genetic variants found between dogs and wolves, many of those being related to genes that control starch digestion (Axelsson et al., 2013) leading domesticated dogs to tolerate and digest starch more efficiently than wolves. There are fewer modifications between domestic and nondomestic cats. As a result of preserved hunting specializations, the Felidae family has a more uniform morphology than other Carnivora (Holliday and Steppan, 2004; Nowak, 2005). Short snouts, powerful jaws, and retractable claws assist in killing prey while large eyes and ears facilitate nocturnal hunting (Nowak, 2005).

It is well accepted that felids have several unique nutrient requirements resulting from idiosyncratic metabolism that must be considered when formulating diets. High protein requirements, specific requirements for the amino acids taurine and arginine, and requirements for vitamin D, niacin, arachidonic acid and pre-formed vitamin A have been well documented in the domestic cat (*Felis catus*). All of these unique requirements, however, are met by a carnivorous diet consisting of animal tissues (MacDonald et al., 1984; Morris, 2002). Domestic cats and managed exotic felids are typically fed commercially prepared diets formulated to meet National Research Council (NRC) (NRC, 2006) or Association of American Feed Control Officials (AAFCO) recommendations.

**Meat-Based Diets for Carnivores**

While substantial nutrition based research has been published for domestic cats, far less has been published directly involving exotic felid species. With more than half of surviving non-domestic felid species being endangered or threatened with extinction (U.S. Fish and Wildlife Service, 2015), this research is critical for sustainable populations and management. It has been demonstrated that domestic cats can serve as an adequate model for
their exotic counterparts in captivity (Clauss et al., 2010; Vester et al., 2010a). Using this information, much of the domestic cat research can be extrapolated to improve captive exotic cat nutrition. Although overall extrapolations from domestic cats can be made for exotic cats, raw meat diets have not been extensively researched in either group of felids. Nutritionally complete raw meat diets have historically been the most popular choice for exotic felids in zoological institutions and have recently received a lot of attention, both positive and negative, in the companion animal industry.

Advantages of Feeding Raw Meat Diets

Benefits of feeding raw meat diets to carnivores have been documented and include higher bioavailabilty of nutrients and improved nutrient digestibility. Cats have several unique nutrient requirements such as a high protein, taurine, arginine, vitamin D, niacin, arachidonic acid, and pre-formed vitamin A. All of these requirements are met by a diet consisting of animal tissues (MacDonald et al., 1984; Morris, 2002). Cooking or processing of these tissues can alter their nutritional content, however. This may lead to nutrient deficiencies or less efficient utilization in cats consuming processed diets.

Impact of Processing and Cooking on Raw Product Nutrient Composition

Processing with heat can reduce the content of valuable nutrients in a diet. Cooking meat (baked) reduces the amount of thiamine in pork loin by 75.0%, riboflavin in beef flank by 66.7%, and niacin in horse fillet by 48.0% (Lombardi-Boccia et al., 2005). Calcium, phosphorus, retinol, and α-tocopherol all decreased 28.2, 19.1, 34.0, and 14.1%, respectively, in grilled beef rib-eye compared with raw (Gerber et al., 2009). Some of the valuable taurine present in animal tissues is also lost with cooking. Taurine is present in highest concentrations in animal tissue and organs but taurine is water soluble and cooking processes
such as boiling and baking have been shown to decrease taurine content (Spitze et al., 2003). Spitze et al. (2003) showed taurine concentrations of beef kidney were reduced 38.7 and 66.2% with baking and boiling, respectively, when compared to the raw beef kidney. Likewise, taurine concentrations were reduced by 55.9 and 76.2% with baking and boiling of pork loin, respectively, compared with raw loin (Spitze et al., 2003).

Beyond high heat cooking such as baking and boiling, the extrusion process to make dry kibble diets can strip diets of certain nutrients. Extrusion is a high temperature (up to 250°C), short-duration (1 to 2 minutes), high pressure (up to 25 MPa) cooking process that may change the functional properties of feed ingredients (Cheftel, 1986). The process relies on melting and gelatinization of starch granules, and too high of a lipid content (more than 6-7%) will inhibit this process. For this reason, extruded diets are inherently higher in starch and lower in lipids than raw diets. In order to increase lipid content of kibble diets, additional fat must be added after the extrusion process. Additionally, reductions of lipid availability from 20-55% have been documented for raw versus extruded maize and wheat (Delort-Laval and Mercier, 1976; Nierle et al., 1980). Amino acids also form complexes with carbohydrates during extrusion, known as Maillard reactions. These reactions along with protein cross-linking and denaturing, can lower protein digestion and utilization compared to non-processed diets that have not undergone these reactions (Camire et al., 1990).

Specific amino acids are affected by the extrusion process. Sulfur containing amino acids (methionine and cystine) are sensitive to oxidation and desulphurization during extrusion. This is significant because methionine is the first limiting amino acid for cats, important for growth and overall metabolism, and cystine is an important amino acid for hair and skin health (NRC, 2006). In a protein-enriched biscuit, methionine, arginine, and cystine
concentrations were reduced by as much as 28.6, 21.3, and 14.3%, respectively, at temperatures of 193°C and above (Björck et al., 1983). Lysine seems to be the most affected amino acid, likely because of its free amino group increasing severity of Maillard reactions (Björck and Asp, 1983). Björck and colleagues also demonstrated a 37% loss of lysine in wheat flour when extruded at temperatures of 210°C, and a 37% reduction at 171°C (Björck et al., 1984). Similar results of 40% lysine loss in protein-enriched biscuits at extrusion temperatures of 210°C have also been shown (Noguchi et al., 1982).

Vitamin C is extremely sensitive to heat and is affected by the extrusion process. Vitamin C losses of 20-68% have been reported in cereals such as potato flakes when extruded at high (180-250°C) temperatures (Camire et al., 1990; Cheftel, 1986). Camire et al. (1990) also showed losses in vitamin C concentrations were affected by shelf-life time, with 87% loss after one month of extrusion and storage. Additionally, the authors documented recovery was as low as 21 and 15% for thiamin and riboflavin, respectively, in extruded samples compared to pre-extruded samples. Other nutrients such as vitamins A and E, as well as linoleic, linolenic, and arachidonic acids are thought to decline with extrusion, but more work is needed to determine specific loss amounts.

**Influence of Raw Meat-Based Diets on Gastrointestinal Tract Health**

Literature has documented improved nutrient digestibility of cats fed raw meat diets compared with canned or extruded diets, especially for fat and protein. This is a noteworthy characteristic because diets high in protein content, but low in protein digestibility, can lead to more protein reaching the large intestine. This leads to more fermentation and putrefactive components such as ammonia, short chain fatty acids (SCFA), phenols, and indoles being produced. All of these may negatively impact gastrointestinal health (Vester et al., 2008).
In addition to feeding a diet that has high digestibility of fat and protein, gastrointestinal tract problems may be mitigated by providing adequate fiber in the diet. Fiber has not been thought to play a significant role in a carnivorous diet until recently, and the type of fiber may be of unique consideration. Typical commercial raw carnivore diets utilize beet pulp (soluble and fermentable) or cellulose (nonsoluble and non-fermentable) as fiber sources. While these two fiber sources are very typical in raw diets some variation in how cat species utilize them may exist. Smaller cat species, including cheetahs (*Acinonyx jubatus*), have been shown to tolerate beet pulp as a source of fiber while larger species, such as tigers (*Panthera tigris*), require more cellulose to limit fermentation. Non-fermentable fibers, such as cellulose, provide the bowel with tactile stimulation which induces colonic motility and weight (Bueno et al., 2000b) while fermentable fibers will induce chemical changes in the bowel and production of short chain fatty acids (SCFA), which can be absorbed for energy (Bueno et al., 2000a). Too much fermentable fiber in diets may result in excess production of SCFA, increasing passive transport absorption and possibly resulting in looser stools compared to stools of animals receiving less fermentable fiber sources. This was shown with fecal scores being higher (looser) in exotic felids fed a diet containing 2% beet pulp (3.4) compared to 2% cellulose (2.7) and, furthermore, an inclusion of 4% beet pulp (3.9) resulted in higher fecal scores than inclusion at 2% (Kerr, 2012). Differences in fiber type also led to differences in macronutrient digestibility. For cheetahs, inclusion of beet pulp results in higher crude protein digestibility (95%) compared to tigers (92%), while for jaguars and tigers, inclusion of cellulose resulted in higher crude protein digestibility (96 and 95%, respectively) than beet pulp (93 and 92%, respectively). Optimally, it was suggested a complete raw diet would include a combination of fermentable and non-fermentable fibers to
achieve optimal fecal scores, digestibility, and intestinal health for a variety of felid species (Kerr, 2012).

Intake of plant fiber, such as cellulose, would be extremely low in wild felid diets other than components within prey digestive tracts. As a result, the concept of animal fiber has received growing attention in recent years. Animal fiber can be thought of as raw bone, cartilage, skin, hair, and other poorly digestible parts of animal tissue. In the wild, consumption of animal viscera, which would include bone, cartilage, and several other components, is expected to meet the fiber needs of the animal (Boler, 2009). Recently, a study compared fourteen captive cheetahs fed diets of either whole rabbit carcasses or chunks of beef muscle meat. When the cheetahs consumed the whole prey diet, fecal phenols and indoles were reduced by 65.54% and 61.38% compared to fecal samples when cheetahs were fed muscle meat. Additionally, acetate to propionate ratios increased from 2.9 to 6.0 when cheetahs were fed whole prey, further indicating a reduced fermentation pattern leading to fewer toxins or putrefactive compounds produced in the bowel. This is thought to be attributed to the intake of animal fiber from the whole rabbit carcass (Depauw et al., 2013).

**Nutrient Digestibility of Raw Meat-Based Diets**

Nutrient digestibility of raw meat diets has been documented recently in domestic and exotic felids. While the literature is not overly abundant, results consistently show high nutrient digestibility of raw meat diets. Felid species are particularly efficient at digesting dietary fat. Up to 60% of total energy has been estimated to come from fat in large cat diets and cats can digest diets with large amounts of fat (up to 67% energy as fat) (Scott, 1968).

One study reported mean apparent digestibility values of 81.0% for dry matter (DM), 88.0% for organic matter (OM), 87.0% for crude protein (CP), 97.0% fat, and 90.0% gross
energy (GE) for a raw horsemeat-based diet fed to four different exotic felid species: cougars (Felis concolor); leopards (Panthera pardus); lions (Panthera leo); tigers (Panthera tigris) (Barbiers et al., 1982). In 2008, another study reported similar average apparent digestibility values of 88.3% for DM, 88.0% for OM, 92.9% for CP, 95.1% for fat, and 92.4% for GE with a raw beef diet fed to 20 captive large exotic felids of five different species [bobcats (Lynx rufus; n=2), jaguars (Panthera onca; n=4), cheetahs (Acinonyx jubatus; n=5), Malayan tigers (Panthera tigris corbetti; n=4), and Siberian tigers (Panthera tigris altaica; n=5)] (Vester et al., 2008). In 2010, similar average values for DM, OM, CP, fat, and GE digestibilities (87.6, 96.0, 92.6, 93.8, and 94.1%, respectively) were reported for raw beef-based and horsemeat-based diets (84.3, 94.3, 95.1, 93.9, 94.2%, respectively) fed to domestic cats ((Felis catus) (n=9)) and four captive exotic felid species [cheetahs ((Acinonyx jubatus) (n=5)), jaguars ((Panthera onca) (=4)), Malayan tigers ((Panthera tigris jacksoni) (n=3)), Siberian tigers ((Panthera tigris altaica) (n=5))] (Vester et al., 2010a). More recently, average apparent digestibility values of DM, OM, CP, fat, and GE as 85.6, 88.4, 96.5, 93.6, and 90.9%, respectively, for a raw beef-based and similar values of 86.8, 89.4, 96.1, 95.7, and 91.5%, respectively, for a raw horsemeat-based diet fed to domestic cats ((Felis catus) (n=8)) and four animals of each captive exotic species (African wildcats (Felis silvestris lybica), jaguars (Panthera onca), and Malayan tigers (Panthera tigris jacksoni)) were reported (Kerr et al., 2013).

Studies conducted using domestic cats have demonstrated that raw meat-based diets are better digested than canned or extruded diets. Cats consuming a canned diet had 19.6, 15.3, 18.5, and 18.1% lower digestibility values compared to a raw diet for DM, CP, fat, and GE, respectively (Kendall et al., 1982). The same study also found a dry kibble diet to be
28.6, 20.0, 41.3, and 23.8% less digestible in DM, CP, fat, and GE, respectively, when compared to the fresh meat diet. Another study also saw reductions in digestibilities with a high-protein extruded kibble diet being 9.8, 7.3, 12.5, 4.4, and 7.4% less digestible in DM, OM, CP, fat, and GE, respectively, compared to a raw beef-based diet fed to domestic cats. Cooking the raw diet in this study resulted in small reductions in DM, OM, CP, fat, and GE digestibilities (3.3, 2.2, 0.4, 0.2, and 1.9%, respectively) (Kerr et al., 2012).

Studies of this nature have also been conducted in small exotic cats. In a study using African wildcats (*Felis silvestris lybica*) fed a raw beef diet, digestibility values of 86.0% DM, 90.0% OM, 91.7% CP, 95.5% fat and 91.6% GE were reported. When the cats were subsequently fed a high-protein dry kibble diet, digestibility values for DM, OM, CP, fat and GE were lower by 5.2, 2.8, 8.3, 1.3, and 3.4%, respectively (Vester et al., 2010b). Nutrient digestibility between raw and kibble diets was also different in sand cats (*Felis margarita*). Digestibility of DM, CP and GE were reduced by 12.9, 15.7, and 14.3%, respectively, when sand cats were fed the extruded diet compared to a raw horsemeat-based diet (Crissey et al., 1997). All of these studies reported higher dry matter intakes on the kibble diets, but no change in body weights. This could further suggest a greater utilization of the raw meat diet compared to extruded diets.

**Impact of Processing and Cooking on Raw Product Nutrient Digestibility**

As previously mentioned, heating foods causes some changes to nutrient composition. Heat processing of foods also likely explains the documented reductions in nutrient digestibility. While heat processing does not change the overall crude protein content of the diet, availability and digestibility of certain amino acids does change. Notably, digestibility of methionine, lysine and aspartic acid all decreased from 85.9 to 75.0%, 84.2 to 77.4%, and
78.3 to 40.2% digestibility, respectively, when time of heat processing increased from zero to 25 minutes at 121.1°C with a canned cat food (Hendriks et al., 1999). In addition, digestive enzymes in raw food are thought to be more biologically available, and cooking or processing could reduce activity or deplete these enzymes (Schlesinger and Joffe, 2011). Specifically, phytate digestion was 33% higher in humans who consumed unprocessed diets versus an extruded one (Sandberg et al., 1987), possibly due to loss of phytase activity in extruded diets (Sandberg et al., 1986).

The combination of higher concentration or more available nutrients, higher nutrient digestibility, and possible gastrointestinal benefits make raw meat-based diets an attractive option for carnivore management. The scientific evidence for advantages of feeding raw meat diets over canned or kibble diets is strong, however, reluctance to feed raw meat diets stems from documented disadvantages.

### Disadvantages of Feeding Raw Meat Diets

Although there are clear improvements in nutrient digestibility while feeding raw diets, there also are some disadvantages associated with them. The most common concern associated with feeding raw meat diets is the risk of microbial and bacterial contamination. The microbe genus receiving the most attention in this area is *Salmonella*. *Salmonella* is the leading cause of food-borne illness in the United States, mainly causing infection through consumption of contaminated poultry, eggs, or beef but pork also can harbor the organism. Spread of *Salmonella* among pigs occurs via shedding of the bacteria in the feces. Fecal-oral transmission may cause enterocolitis resulting in diarrheal disease, but infected pigs also may remain subclinical (Carlson et al., 2012).
Cats infected with *Salmonella* also may not show clinical signs of infection. The stools of more than 30 exotic felids from a private collection including snow leopards (*Panthera uncia*) (n=2), leopards (*Panthera pardus*) (n=3), cougars (*Felis concolor*) (n=6), caracals (*Felis caracal*) (n=2), and servals (*Felis serval*) (n=15) as well as a zoo collection including tigers (*Panthera tigris*) (n=7), Asian lions (*Panthera leo persica*) (n=2), African lions (*Panthera leo*) (n=2), snow leopards (*Panthera uncia*) (n=2), cheetahs (*Acinonyx jubatus*) (n=5), cougars (*Felis concolor*) (n=2), and a Canadian lynx (*Lynx canadensis*) (n=1) were assessed. Cats were fed a raw horsemeat-based diet and those from the private collection also received pieces of raw chicken. The study documented the isolation of *Salmonella* from 95% of cats from the private collection and 94% of cats from the zoo collection. Of the cats that tested positive for *Salmonella*, more than 90% showed no clinical signs of illness. Those cats also didn’t show signs of illness over the subsequent year (Clyde et al., 1997). These results suggest an ability of carnivores, particularly cats, to harbor and shed *Salmonella* as a nonpathogenic gastrointestinal bacteria, possibly as an evolutionary adaptation to carnivory. While the intestinal tract is the reservoir for *Salmonellae* (Carlson et al., 2012), a short digestive tract, fast passage rate, and low stomach pH may allow cats the ability to excrete *Salmonella* while remaining asymptomatic.

*Salmonella*, even if non-threatening to the consuming animals, can still affect humans handling infected products. Although there has only been one published report of salmonellosis occurring in cats as a result of being fed a raw diet (Finley et al., 2006), an estimated 1 to 18% of healthy cats still carry the bacteria and shed it in their feces (Sanchez et al., 2002). This, along with raw meat itself, pose threats to humans who may come into contact with contaminated diet or feces. There has not, to date, been a documented case of
human salmonellosis directly associated with feeding raw meat diets to pets (Finley et al., 2006). It is essential that owners practice proper handling and cleaning procedures to reduce risk.

*Trichinella* is a parasitic nematode that mainly infects carnivorous mammals, and also has a history of human infection. Of the ten genotypes of *Trichinella* recognized thus far, *Trichinella spiralis* is especially adapted to infect domestic pigs (Pozio et al., 2009). This parasite is transmitted between pigs through ingestion of infected sources, often via tail-biting or consuming carcasses or garbage that contains infected meat (Greve, 2012). The trade of domestic pigs along with migration of brown rats (*Rattus norvegicus*) likely caused the spread of the parasite around the world (Pozio, 2000) and in its history, *Trichinella* has been detected on all continents with the exception of Antarctica (Pozio, 2007). *Trichinella* species are consumed in muscle meat, where the parasite resides in infected individuals. Once consumed, the worm develops in the small intestine and later migrates to the muscle tissue of the host (Catty, 1969).

*Trichinella spiralis* parasites are highly associated with raw meat, especially pork and horse, and consuming these raw or undercooked meats can result in Trichinellosis. The consumption of raw horse meat has been linked to several cases of Trichinellosis, mainly in France and Italy (Ancelle et al., 1988; Boireau et al., 2000; Pozio and Darwin Murrell, 2006). In areas where it is regularly consumed, bear meat also is a source of *Trichinella* (Hall et al., 2012). The number of incidence of reported Trichinellosis has drastically declined in the United States over recent decades; however, the main source of the parasite has shifted. From 1947 to 1951 the median number of reported human *Trichinellosis* cases was 393. From 1997 to 2001, that number had dropped to 12. Between 2002 and 2007 there were 66 cases
reported. Of those 66 cases, 21 were associated with consumption of bear meat while only 7 were associated with commercial pork consumption (21 associated with bear meat consumption, 2 with noncommercial pork consumption, and others with cougar, deer, walrus and commercial beef consumption) (Kennedy et al., 2009).

The decline in Trichinellosis incidence can largely be attributed to improved farming and management practices in swine production. Heightened regulations have outlawed feeding garbage, improved sanitation, and monitored tail-docking practices (Greve, 2012). Public health programs, improved detection procedures and a *Trichinella*-free certification program monitoring farm practices (U.S. Trichinae Certification Program (Pyburn et al., 2005)) also have aided in infection incidence reduction. Additionally, proper storage (freezing at -29°C for 6 days) will kill most *Trichinella* species (Greve, 2012).

Aujeszky’s disease, also known as pseudorabies, is a part of the herpesvirus group and dates back to the nineteenth century when it was first discovered in cattle; it wasn’t until the 1920’s that the virus was found to infect pigs (Nauwynck et al., 2007). The disease was exacerbated in the 1950’s 60’s and 70’s with the intensification of swine production and breeding. Between 1974 and 1977 the number of reported cases jumped from 125 to 1,256 (Lee and Wilson, 1979). Pseudorabies is shed in nearly every bodily secretion/excretion and transmitted via direct contact with infected animals or material (bedding, water, carcasses), often through the oral or nasal cavity (Mettenleiter et al., 2012). Once the virus enters the body it replicates in the upper respiratory tract then proceeds to spread to the brain and eventually organs, particularly the reproductive organs (Nauwynck et al., 2007). Presence in the reproductive organs, plus the ability of the virus to cross the placental barrier, cause the disease to result in abortions in pregnant sows. Infected animals may also have symptoms of
ataxia, coughing, sudden death, or may be subclinical, with young piglets being most severely affected (Mettenleiter et al., 2012).

Cats acquire the disease through ingestion of infected meat, namely pork, and show symptoms of depression, anorexia, self-mutilation, and inevitably death within 48 hours of displaying clinical signs (Thiry et al., 2013). While vaccines to protect pigs from this virus have been developed, these vaccines are not acceptable for cats (Thiry et al., 2013). In 1994 raw pork meat also was the alleged cause of pseudorabies in four captive brown bears (Ursus arctos) in Italy. Pork was ruled to be the source of infection because all four bears fed raw pork died within 24 hours of showing signs, while one bear, not fed pork, survived (Zanin et al., 1997). Improvements in herd management and sanitation as well as the use of vaccines can control the disease in swine. The virus can be deactivated thermally or through use of disinfectants, so through sanitation regulations in addition to herd testing, proper carcass disposal, feral swine monitoring (which can also harbor and transmit the virus), and several other factors, the USDA, National Pork Producers, and other groups have developed an eradication program. By the late 1990’s most U.S. states had made substantial strides towards eradication of pseudorabies and by 2004 all 50 U.S. states were deemed pseudorabies free (USDA, 2008). Monitoring and inspection continues to ensure that the virus does not reemerge in commercial swine operations.

Another parasite concern in raw meat diets is Toxoplasma gondii. Toxoplasma is common in many animals used for food including cattle and horses, but especially sheep and pigs. In one large scale study, isolation of Toxoplasma gondii ranged from 0.3 to 92.7% of pigs on five different farms (Dubey and Jones, 2008). No vaccine is available to control Toxoplasmosis, so prevalence of the parasite depends on husbandry and management.
Rodent control, removing pig carcasses, and not feeding undercooked garbage that may be contaminated are management practices that may help control infection (Lindsay et al., 2012). Transmission between animals typically occurs via ingestion of contaminated water or food with many infections remaining subclinical. If clinical signs do occur in pigs they may include diarrhea, incoordination, or coughing.

Cats also can excrete infectious *Toxoplasma* oocysts in their feces, and this is a major vector of environmental contamination and human infection. Cats obtain the parasite through ingestion of raw/undercooked meat infected with the protozoa, which can reside in any edible portion of an infected animal (Hill and Dubey, 2002). Cats exacerbate contamination because through the ingestion of just one *Toxoplasma* cyst, cats amplify the parasite and can excrete millions of oocysts (Hill and Dubey, 2002). One study with domestic cats reported 85% of cats tested positive for *Toxoplasma gondii* antibodies when fed a raw meat or viscera diet (Svoboda, 1987). Infection in the cat often remains subclinical, but may manifest as fever, anorexia, or ocular inflammation but is usually not lethal (Elmore et al., 2010). Control of infection in cats can be controlled through cooking or freezing of meat in the diet because *Toxoplasma* parasites are susceptible to extreme temperatures (Lindsay et al., 2012).

Microbial and bacterial contaminations are of high concern when feeding any raw meat product. To mitigate these concerns, many commercially available raw meat diets for the pet industry utilize interventions to decrease pathogens. High pressure pasteurization (HPP) (Rastogi et al., 2007), irradiation (Farkas, 1998), and organic acids (such as lactic acid) (Ricke, 2003; Vandenberghe, 1993) may be employed to mitigate microbial risk in raw meat products. Good husbandry and farm practices (Greve, 2012; Lindsay et al., 2012),
swine vaccines (Thiry et al., 2013), and proper freezing (Lindsay et al., 2012) all combine to further mitigate pathogenic risks of raw meat diets.

Environmental Enrichment for Managed Felids

Shepherdson and others (1998) broadly defined environmental enrichment as, “an animal husbandry principle that seeks to enhance the quality of captive animal care by identifying and providing the environmental stimuli necessary for optimal psychological and physiological well-being.” In its most general definition, enrichment is intended to improve the well-being of an animal. The assessment of animal well-being is often carried out by ensuring that the five freedoms are met. These freedoms include freedom from: hunger and thirst; discomfort; pain, injury, and disease; fear and distress; and freedom to express normal patterns of behavior (FAWC, 2009).

Environmental enrichment encompasses a wide range of actions and processes, so it is often easier to define it in terms of its purpose rather than its implementation (Shepherdson et al., 1998). At its core all enrichment shares the same goals. Environmental enrichment should increase the number and range of normal (wild) behaviors, positive utilization of environment, and animal’s ability to cope with behavioral and physiological challenges while decreasing development and frequency of abnormal behaviors (Young, 2003). To accomplish this, several different types of enrichment can be employed including: social (grouping animals together and human interaction), occupational (physiological enrichment often involving control of environment and exercise such as running), physical (enclosure size/complexity and accessories (i.e. furniture, toys, and puzzles)), sensory (visual, auditory, olfactory, taste), and nutritional or biologically relevant food (diet delivery method (frequency/schedule) and type (novel, browse, treats)) (Bloomsmith et al., 1991; Young,
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2003; FASS, 2010). Because an animal’s environment is prone to change, enrichment should be a dynamic process that changes along with it.

**Biologically Relevant Enrichment**

When planning and designing enrichment, an animal’s natural history should be carefully considered (Mellen and Sevenich MacPhee, 2001). It has been highlighted that animals have biological interests and natural instincts as well as physical and physiological needs that are genetically encoded (Rollin, 1985), such as hunting for felids. If these biological needs are suppressed or not met, the animal can be negatively affected.

Enrichment that aims to fulfill the natural needs of an animal will be most effective. Lack of regard for the evolution and natural history of an animal can account for many of the problems associated with welfare studies in general (Dawkins, 1998).

If natural history and behaviors are taken into account when planning enrichment programs, species specific behaviors can result. This is true for all species ranging from laying hens (Smith et al., 1993) to seals (Hunter et al., 2002). Increasing the occurrence of natural behaviors (i.e. behaviors observed of wild animals) is often a goal of captive animal management, so biologically relevant enrichment is not only ideal but is vital. Beyond increasing natural behaviors, enrichment that elicits natural behaviors can also reduce the stress response (noted by less fighting and vocalization by care staff in mice (Chamove, 1989)) as well as significantly lessen fear responses and injury by 0.55 on a 4 point injury risk scale (Reed et al., 1993). Furthermore, providing more complex environments to captive animals has been shown to heighten brain complexity (Greenough and Volkmar, 1973), quicken habituation by improving maze time by 16 seconds in the first day (Larsson et al., 2002), as well as aid in brain plasticity and rehabilitation (Johansson and Belichenko, 2002).
Non-Nutritive Value of Meat By-products as Biologically Relevant Enrichment for Felid Management

In North American zoos, diets of carnivores commonly consist of ground raw meat diets, typically horse or beef-based. While these ground diets are nutritionally complete, they do not fulfil other non-nutritive requirements of carnivores. The non-nutritive aspects of food include diet consumption activities (locating, capturing, and killing prey using their carnassial teeth and powerful jaws to rip, tear, and pull flesh from their prey), oral health, and psychological aspects of the feeding process (Lindburg, 1988). In the wild, many felid species spend considerable time searching, capturing, and consuming prey. Lindburg (1988) highlighted that Bengal tigers covered 16 to 32 kilometers on an average nightly hunt with only 5% success rate on those hunts. Furthermore, a cheetah with cubs spent approximately 40% of her time hunting (Lindburg, 1988).

In captivity the “need” to express hunting behavioral sequencing is vastly reduced, because food is easily available with little competition. Therefore, felids may fill their behavioral repertoire with other activities and one area of concern has been the occurrence and presentation of stereotypies. Many observed and documented stereotypies occur just prior to feeding time (Clubb and Vickery, 2006) and pacing has been observed to be the most common pre-meal stereotypy in ocelots (*Leopardus pardalis*) (Weller and Bennett, 2001). This may be due to frustration arising from diet or the feeding process. Environmental enrichment has been used more extensively over recent years to combat stereotypic behaviors that arises from captivity. A review of 25 zoo-conducted stereotypy studies found that offering or increasing enrichment reduced stereotypic behavior expression in 53% of cases (Swaisgood and Shepherdson, 2005).
Considering the natural behaviors of wild felids is useful for guiding the goals of captive animal feeding programs. Felids fed carcasses in captivity were observed to exercise use of their feet, teeth, jaws, and head to tear meat from bones. Cats fed a ground diet displayed none of these behaviors (Bond and Lindburg, 1990). Offering captive felids live, whole prey would most closely mimic the feeding of their wild counterparts, but this is unlikely in North American zoos because of negative public perception and humane treatment of prey animals (Mellen et al., 1998). A plausible alternative would be to use large, meat-based enrichment items to fulfill these non-nutritive requirements and reduce unwanted behaviors. Items that require chewing or ripping for consumption can be used alongside a typical ground diet to evoke more natural feeding behaviors (Bond and Lindburg, 1990).

In addition to behavioral concerns, serious health issues also have been associated with a lack of natural feeding behaviors. In 1981, animal managers at the San Diego Wild Animal Park noted abnormal oral health in several of their adult cheetahs. Cheetahs were found to have misaligned molars, leading to irritation of the oral mucosa and infection developed due to decaying food that was impacted in the compromised oral cavity. This condition is termed focal palatine erosion (FPE). Following the San Diego assessment, 59 more cheetahs from other institutions were examined and evaluated for the occurrence of FPE. Results showed that 15 of 59 evaluated cheetahs had some stage of FPE, and all were fed commercially prepared ground raw diets. The disease was absent in 39 animals that received whole prey as part of their diet. It was concluded that lack of biting, tearing and pulling feeding behaviors could lead to development of FPE through atrophy resulting from lack of mastication (Fitch and Fagan, 1982). Since then, FPE has been found to be most
common in captive opposed to wild felids, especially Cheetahs (*Acinonyx jubatus*) (Zordan et al., 2012).

Changes in morphology have been associated with captivity since the late 1800’s and many of those changes have been attributed to diet or feeding pattern (Zuccarelli, 2004, Smuts et al., 1978, Duckler, 1998). Morphology, particularly of the skull, is correlated with the mechanical properties that foods possess and changes in skull morphology between captive and wild felid counterparts may be due to lack of naturalistic diets that require manipulation by the animal (O'Regan and Kitchener, 2005). Skulls of 25 tigers and 107 lions collected in a museum were compared. The individuals were of varying origins including wild, zoo, and circus animals. Thirteen of the inspected skulls showed a significant discrepancy in one area of the skull where muscle attachment is dominant and complex, the sagittal crest. Of these 13 animals, twelve were housed in captivity (Duckler, 1998). Because formation of the sagittal crest is closely related to muscle use, lack of use may be a likely cause of these malformations. Wild animals feed at irregular intervals that depend on kill success, and feeding regularly in captivity has been thought to cause accelerated growth of the skull resulting in captive animals having larger skulls than their wild counterparts (Smuts et al., 1978). Shorter skulls and reduced cranial volumes in captive versus wild lions from Africa also have been noted (Hollister, 1917).

Various types of bones and other prey components can help prevent atrophy of oral muscles and mitigate changes in skull morphology by stimulating chewing and manipulation. Caloric contribution of these items should not be overlooked, however. Two items commonly used as enrichment, horsetail and beef shank, contain roughly 1,050 and 7,150 kilocalories on an as-fed basis, respectively (Felicetti et al., 2008). When edible enrichment items are
offered and particularly consumed, the regular diet of the animal should be adjusted to prevent overfeeding. Additionally, the high concentrations of some minerals in bones, such as calcium and phosphorus, should be considered and adjusted for in the diet when these items are consumed.

**Additional Values of Environmental Enrichment**

In zoo research, because measurements such as blood samples are often impractical to obtain repeatedly, behavior is often used to evaluate enrichment programs. Monitoring behavioral characteristics and responses to environmental changes can aid in the development of behavioral profiles. These profiles consist of descriptions of behaviors that are characteristic of individual animals and are used to tell animals apart from one another. Zoos can then use behavioral profiles to distinguish strengths and weaknesses of each animal and attempt to relate those back to differences in management (Carlstead et al., 2000).

Behavioral profiles also can help point out modifications of behavior an animal makes in response to new stimuli in their environment, termed behavioral plasticity. Importance of plasticity, or flexibility, in behavior goes back to an animal’s ability to cope with change. Associative learning and exploratory behavior are key factors in behavioral plasticity (Mason et al., 2013), both of which, as previously highlighted, environmental enrichment improve and increase.

Enrichment is necessary and, at some levels, required (AZA, 2014). Providing enrichment for animals can benefit more than just the animal itself. Over the past several decades, the purpose and philosophy of zoos has shifted and become more complex. Whereas zoos were once meant purely for entertainment, now they have goals of species population sustainability and public education. When the average zoo visitor spends as few as 12
seconds at an individual animal exhibit, education efforts can be limited (Altman, 1998). Activity of an animal greatly influences guest duration at exhibits by as much as 100% (Bitgood et al., 1986). Additionally, animal activity directs guest conversation and attention toward the animal (Altman, 1998). If the attention of visitors can be captured and kept by an animal, they will remain at that exhibit longer increasing zoo opportunity for educational goals and directives.

Zoo visitors also have become more aware of stereotypic behaviors and their negative impact on animal health. In one study, half of surveyed zoo guests correctly identified an animal that was engaging in stereotypic behaviors. Not only did visitors think the animal wasn’t behaving naturally when performing these stereotypic behaviors, but they also rated the behavioral welfare of the animal lower than when stereotypic behaviors were absent (Godinez et al., 2013). This has led to pressure on zoos from the public to offer enrichment and attempt to increase the welfare of their animals (Young, 2003). Additionally, enrichment must be a documented component of husbandry for Association of Zoos and Aquariums (AZA) accreditation (AZA, 2014).

Sustainability and breeding programs can benefit from environmental enrichment of zoo animals as well. A decrease in ovarian activity resulting in depressed estradiol concentrations has been noted in cats that were transferred from enriched cages to small, non-enriched enclosures (Moreira et al., 2007). In this way, providing enrichment may help improve breeding success.

Conclusions

Raw meat diets provide advantages and disadvantages for exotic felid management. Macronutrient and energy digestibility studies with beef, poultry, and horsemeat-based diets
have provided a basic understanding of digestibility coefficients in domestic and exotic felids but more work is needed. Specifically, other protein sources such as pork need to be evaluated. This is an issue because of the prevalence in food sensitivities and intolerances of animals, leading to digestive and overall health issues such as irritable bowel disease and colitis. With the digestibility coefficients of beef- and horsemeat-based diets being available from several previous studies with exotic felids, they can be used as a benchmark for new, alternative diets. Investigation into the digestibility and adequacy of a novel protein source may serve to help remedy some digestive problems facing captive animals as well as improve overall health and add variety.

Additionally, using by-products from pork production facilities to make these alternative diets can serve multiple purposes. Production plants are looking to add value to their by-products while zoological institutions are looking for sources of quality diets and enrichment items for their animals. Producers add value to their products and zoos simultaneously get more variety for their animals. This enrichment can lead to improved health and welfare along with behaviors that will benefit exotic animals when it comes to reintroduction, breeding, and conservation efforts.

Literature Cited


Felicetti, L., C. C. Kearney, L. Woodward, and E. S. Dierenfeld, 2008, Proportion of soft tissue in selected bone cuts fed primarily as enrichments to large carnivores: Zoo Biology, v. 27, p. 154-158.


Kerr, K., 2012, Nutritional evaluation of raw meat and whole prey diets for domestic and exotic cats (Doctoral dissertation), University of Illinois at Urbana-Champaign.


Nierle, W., A. W. ElBayya, K. Seiler, B. Fretzdorff, and J. Wolff, 1980, Changes of grain components during extrusion with a twin-screw extruder [maize, wheat]: Getreide, Mehl und Brot (Germany, FR), v. 34.


NPB, 1999, Case studies of value added pork production & marketing, National Pork Board.


SDSU, 2015, Swine Grading, Brookings, SD, South Dakota State University.


SSR, 2014, Unpublished, Sustainable Swine Resources, LLC.


Swaisgood, R. R., and D. J. Shepherdson, 2005, Scientific approaches to enrichment and stereotypies in zoo animals: what's been done and where should we go next?: Zoo Biology, v. 24, p. 499-518.


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 Biology, v. 27, p. 126-36.


CHAPTER 3

INFLUENCE OF PORK AND PORK BY-PRODUCTS ON MACRONUTRIENT, ENERGY DIGESTIBILITY AND PALATABILITY IN LARGE CAPTIVE FELIDS

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Abstract

Two experiments were conducted to evaluate the digestibility and palatability of a pork-based raw diet for zoo managed felids. Currently two protein sources (beef or horse) comprise the majority of raw meat diet formulations for exotic carnivores in zoological institutions. Pork-based diets have traditionally not been fed to managed exotic carnivores and nutrient digestibility of pork has not been adequately evaluated in these animals. The objectives of this study were to determine if a pork-based diet had similar apparent total tract macronutrient digestibility and fecal scores as standard zoological carnivore diets formulated with either horse or beef, in large exotic felids and determine how palatable a pork-based diet would be to managed felids. Dietary treatments consisted of four raw meat diets: one horse-based (Horse), two beef-based (B1, B2), and one pork-based diet (Pork). Fecal scores also were evaluated. Dry matter and crude protein apparent digestibilities were higher (P<0.05) in cats fed Pork (87.97 and 95.74%) compared with cats fed Horse (83.59 and 92.71%) and B2 (85.60 and 93.14%). Apparent organic matter digestibility was higher (P<0.05) in cats fed Pork (90.76%) than cats fed Horse (88.53%). Apparent crude fat digestibility values were high across all treatments but were higher (P<0.05) in cats fed Pork (98.51%) compared with cats fed B1 (95.51%) or B2 (96.45%). Gross energy digestibility values were higher in cats
fed Pork (92.38%) compared with B1 (90.21%). Average fecal scores were 2.30, 2.94, 3.42, and 3.54 for Horse, Pork, B1 and B2, respectively; and were different between every treatment with the exception of B1 and B2 which were not statistically different. The pork diet was selected in 24 of 37 total (64.86%) observations of first approached and 23 out of 33 total (69.70%) observations for first tasted, compared to a beef-based raw diet. Based on results, the evaluated pork-based diet had similar or slightly higher apparent total tract macronutrient digestibility and palatability compared with standard zoological carnivore formulations. In conclusion, pork-based diets could be included among dietary options for large zoo felids.

Key words: raw, pork, palatability, exotic, cats, novel

Introduction

In zoological institutions, carnivores are typically fed raw meat diets containing beef or horsemeat as protein sources. Although research addressing health benefits of raw meat diets in felids are lacking, some studies have shown these diets are highly digestible with macronutrient digestibilites ranging from 84.2 to 96.9% (Kerr et al., 2013; Vester et al., 2010a; Vester et al., 2008) in large exotic felids including jaguars (Panthera onca), Malayan tigers (Panthera tigris corbetti), cheetahs (Acinonyx jubatus), and Amur tigers (Panthera tigris altaica). A raw pork-based diet has not previously been evaluated and is currently not commonly fed in zoological institutions.

During commercial manufacture of human grade pork products, up to 40% of live pig weight may be discarded to rendering facilities (SSR, 2014) and the typical range of dressing percent for the swine industry is 68-77% (SDSU, 2015). Nutritionally rich by-products including bones, liver, spleen, and tongue may be among the items discarded to the rendering
process. From 1927 to 2009, more than 70% of rendering facilities closed (Bisplinghoff, 2006; Meeker, 2009) mainly because of heightened regulations from the Environmental Protection Agency (Morrow and Ferket, 2001). This has resulted in higher costs associated with rendering because of transportation fees, leading pork producers to evaluate other avenues to add value to their products (Buhr, 2004; NPB, 1999). Utilizing these by-products in a raw meat diet for managed carnivores, without the cost of rendering, may be a beneficial avenue.

Previously, 27 raw pork by-products were analyzed for chemical composition and from these analyses, a raw meat diet was formulated to meet or exceed nutrient requirements of the domestic cat (NRC, 2006). The diet included a vitamin/mineral premix that used cellulose and beet pulp as carriers and fiber sources. This diet was used in the present study to evaluate if a pork-based diet was comparable to more commonly used beef or horsemeat-based raw meat diets in relation to macronutrient digestibility.

Cats have been shown to develop aversions to foods comprising the majority of their diets for extended periods of time, known as the monotony effect. Cats may also develop an aversion to foods they have not consumed before, especially if they have been fed one type of diet for much of their life, a behavior known as neophobia (Bradshaw, 2006). Neophobia can cause issues with management techniques because a change in diet may result in an animal ceasing to eat. For this reason, it is important to evaluate the palatability of new dietary options for managed felids as additional options may be useful for animal managers.

The objectives of this study were to determine the apparent total tract macronutrient digestibility, fecal scores, and palatability of a pork-based diet compared with standard zoological carnivore diets formulated with either beef or horse, in large captive exotic felids.
We hypothesized that a pork-based diet would be as digestible and palatable as typical beef or horse-based raw meat diets, and could be included among dietary options for captive large exotic felids.

Materials and Methods

Experiment 1- Digestibility

Animals

Ten exotic cats were used (7 male, 3 female), ranging in age from 7 to 17 years 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 prior to the study for at least 6 months. Cats were individually housed at Omaha’s Henry Doorly Zoo & Aquarium (OHDZA) and cared for by zoo staff. Water was provided ad libitum throughout the study. All animal procedures were approved by Omaha’s Henry Doorly Zoo & Aquarium’s Animal Care and Use Committee (IACUC) before animal experimentation. All dietary treatments were fed isocalorically daily to maintain animal body condition based on previous diet caloric intakes.

Diet Composition

Four commercially prepared raw meat-based dietary treatments were analyzed for chemical composition and evaluation in the present study (Table 3.1). Dietary treatments consisted of one horse-based (Nebraska Brand: Premium Feline Diet), two beef-based (Natural Balance: Zoo Carnivore Diet (B1) and Nebraska-Brand: Special Beef Feline Diet (B2)), one pork-based (Sustainable Swine Resources: Carnivore Essentials). Ingredients of dietary treatments are listed in Table 3.2. Each dietary treatment was subsampled, dried at 55
oC, ground through a 2-mm screen (Wiley mill 3379-K35, Thomas Scientific, Swedesboro, NJ) and analyzed for chemical composition. Dietary treatments were analyzed for dry matter (DM) (Method 934.01) and organic matter [OM ((Method 942.05) AOAC, 2006)]. Crude protein (CP) 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 (GE) was determined by bomb calorimetry (model 6200, Parr Instrument Co., Moline, IL). Crude fiber (CF) was determined by Midwest Laboratories [(Omaha, NE) (AOCS Ba6a-05 (Thiex, 2008))]. Total dietary fiber (TDF) also was determined at OHDZA (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. All chemical analyses were conducted at Iowa State University unless otherwise noted.

Experimental Design

The experimental design was a randomized crossover with animals being randomly assigned to one of four dietary treatments each period, resulting in every cat receiving each diet for one period. Animals were fed isocalorically based on prior gross energy intake to maintain weight and/or body condition. Each of the four treatment periods consisted of ten days for diet adaptation followed by four days of sample collection. During each day of collection periods, total food intake and fecal output were collected and recorded and feces were scored for each individual. Feces were evaluated using a scale of 1 to 5 where: 1=hard, dry pellets; 2=dry, well-formed; 3=soft, moist, formed; 4=soft, unformed; 5=watery liquid (Felid TAG, 2014).
Energy and Macronutrient Digestibility

Total fecal samples were weighed and scored daily for each cat then pooled for each collection period and subsampled to measure apparent total tract digestibility. Fecal samples were then dried at 55°C and ground through a 2-mm screen (Wiley mill 3379-K35, Thomas Scientific, Swedesboro, NJ). All fecal samples were analyzed for DM, OM, CP, GE, and fat concentrations using methods previously described for diet analyses. Apparent total tract digestibility values can be found in Table 3.3 and were calculated using the equation as follows:

\[
\frac{(\text{nutrient intake} - \text{fecal output})}{(\text{nutrient intake})} \times 100.
\]

Digestible energy values were calculated using the following equation: (kcal/g energy in diet * energy digestibility of respective diet). Metabolizable energy of diets were calculated using modified Atwater values (8.5 kcal/g fat, 3.5 kcal/g protein, 3.5 kcal/g carbohydrate) multiplied by fat, protein, and carbohydrate content of each diet. Carbohydrate content of diets was calculated by finding nitrogen free extract in the following equation: (100-(%ash+%CP+%fat+%TDF)). Due to assay error, NFE of some diets was a negative number, in which case a value of zero was used for NFE. ME was also calculated using the NRC equation: (ME=DE-(0.77 * g protein in diet)) (NRC, 2006).

Statistical Analysis

All data were analyzed using the Mixed Models procedure of SAS® (SAS Institute, Cary, NC). Data from all cats were averaged within diet because low numbers of individual species. The fixed effects of diet and period were tested and cat 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- Palatability**

A palatability trial was conducted using seven large exotic cats including, cheetahs
(*Acinonyx jubatus*; n=2), jaguars (*Panthera onca*; n=2), puma (*Puma concolor*; n=1), African
lion (*Panthera leo*; n=1) and Bengal tiger (*Panthera tigris tigris*; n=1). One cheetah had to be
removed from the study for unrelated medical reasons and data from that cat was not
considered, resulting in data from six animals for this study. A two-bowl preference test
(Griffin, 2003) was utilized with the zoo’s typical carnivore diet (Nebraska-Brand: Special
Beef Feline Diet) and the pork-based diet (Sustainable Swine Resources: Carnivore Essentials). The study was conducted over seven consecutive days, with the offering position
(left or right) of each diet switching daily. The diet that was first approached and first tasted
was recorded daily for each individual animal.

**Results**

**Experiment 1- Digestibility**

**Diet Composition**

Macronutrient composition of diets could not be statistically analyzed, but there were
numerical similarities and differences in composition. Composition was similar across all
dietary treatments and are presented in Table 3.1. Dry matter (DM) ranged from 31.6 to
35.6%. Organic matter (OM) and gross energy (GE) values ranged from 91.9 to 94.6% and
6.0 to 6.4 Kcal/g, respectively. Crude protein (CP) concentrations were similar between the
pork diet and the first beef diet (B1) (58.5 and 58.0%, respectively) while the horse and
second beef diet (B2) (53.2 and 51.9%, respectively) were similar. Fat concentrations were
similar between the pork, horse, and B1 diets (28.9, 31.0, and 31.0%, respectively), but the B2 diet was approximately 18% higher in fat (35.8%).

**Energy and Macronutrient Digestibilities**

Dry matter and caloric intake (GE) did not differ statistically between any of the dietary treatments in this study and ranged from 546.49 to 612.34 grams and 3292.61 to 3804.60 kcals per day for dry matter and GE intake, respectively. Fecal output did differ (P<0.05) between diets and is presented in Table 3.3, along with dietary intake. Dry matter, organic matter, and crude protein digestibility values (87.97, 90.76, and 95.74%, respectively) for Pork were numerically highest and statistically higher (P<0.05) than Horse (83.59, 88.53, 92.71%, respectively). Dry matter and crude protein apparent digestibilities also were higher (P<0.05) in cats fed Pork compared with B2 (85.60 and 93.14%, respectively). Apparent crude fat digestibility values were high for all treatments but were different (P<0.05) in cats fed Pork (98.51%) compared with cats fed B1 (95.51%) or B2 (96.45%). Gross energy digestibility values were higher (P<0.05) in cats fed Pork (92.38%) than those fed B1 (90.21%). Average fecal scores were lowest (P<0.05) for Horse (2.30) and highest (P<0.05) for the two beef diets that did not differ from one another (3.42 and 3.54 for B1 and B2, respectively) with Pork being intermediate and different (P<0.05) than Horse or beef diets (2.94) (Table 3.3).

Using energy digestibilities from the current study, digestible energy values for the Pork, Horse, B1, and B2 diets are 5.76, 5.45, 5.47, and 5.84 kcal/g, respectively. Modified Atwater factors yield ME predictions of 4.56, 4.52, 4.66, and 4.86 kcal/g, respectively, and the NRC equation predicts ME of 5.30, 5.04, 5.02, and 5.44 kcal/g for the Pork, Horse, B1, and B2 diets, respectively (Table 3.3).
**Experiment 2- Palatability**

Observations of diet first approached and first tasted are presented in Figure 1. One cheetah was not observed eating on the first four days of the study, and eventually was removed from the study for unrelated medical reasons and is not included in data presented for this study. Data were missing for one tiger on day five of the study due to keeper recording error. Of 37 total observations for first approached, the pork diet was selected in 24 (64.86%) observations. The pork diet was selected in 23 out of 33 (69.70%) total observations for first tasted. Statistical analysis was not performed on this data because of small sample size and short duration.

**Discussion**

Our objective was to determine if a pork-based diet had similar apparent total tract macronutrient digestibility, fecal scores, and palatability compared to 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 age and species affects was not an intention of this study. With regard to species, few differences in digestibility have been shown between various felid species (Vester et al., 2010) and significant digestive difference between sexes are not typically seen (Vester et al., 2008; Wynne, 1989). Although some studies have been conducted evaluating raw meat diets in large exotic managed cats, pork-based raw meat diets have never been investigated in these species. Additionally, using raw by-products from the pork industry provides valuable nutrients for raw meat diets while potentially adding value to products for pork producers.
Adding a dietary option to the exotic carnivore market is desirable, and a novel protein source may be useful to add variety and help combat gastrointestinal issues. Novel protein sources, such as pork, are valuable because they have been shown to 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) in domestic cats and dogs. Effects of novel protein sources have rarely been studied in exotic felids, and this warrants further research.

In addition to potentially improving gastrointestinal tract health, novel protein sources also can provide dietary variety. Authors are not aware of published research testing effects of providing dietary variety to captive exotic felids, but natural history shows these species are exposed to a vast variety of prey in the wild. Large exotic cat species may feed on up to 30 different kinds of prey in the wild (Lindburg, 1988). Lindburg later stated, “Predicated on the commonsense notion that in its natural state an animal encounters variation in availability, accessibility, and palatability of food items on a regular bases, enrichment through provisioning most often takes the form of adding variety in the types of food items offered, in their mode of presentation, or in increased frequency of provisioning” (Lindburg, 1998). Not only does providing variety more closely mimic natural diet habits, but can also be a source of enrichment for captive animals.

**Experiment 1- Digestibility**

**Diet Composition**

Each diet evaluated contained meat as its first ingredient and largely consisted of raw meat with the exception of the B2 diet that also contained fish meal and soybean meal as sources of protein. The diet composition ranges of DM (31.7 to 35.6%), OM (92.0 to 94.6%),
CP (51.9 to 58.5%), fat (29.0 to 35.8%) and GE (6.0 to 6.4 Kcal/g) found in the present study were similar to composition of raw meat diets reported from previous studies of DM (29.0 to 38.2%), OM (91.5 to 94.6%), CP (44.9 to 64.5%), fat (22.2 to 36.9%), and GE (5.88 to 6.4 Kcal/g) (Kerr et al., 2013; Vester et al., 2008; Crissey et al., 1997). In those that reported it (Kerr et al., 2013; Vester et al., 2008), TDF also was similar in previous studies (4.8 to 8.4%) compared to the current study. All diet macronutrient compositions fell within ranges reported for domestic cat requirements (NRC, 2006).

**Energy and Macronutrient Digestibilities**

Digestibilities for each diet were averaged across all cats, not by species because of low numbers of each species. Macronutrient digestibility values regardless of protein source, were high across all diets. Nutrient digestibility values reported in this study were similar to previous studies that analyzed macronutrient digestibility in large exotic cat species fed beef or horse-based raw diets. Previous studies reported 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 values that were all similar to the ranges of digestibility values observed in the present study that included 83.6 to 88.0% DM, 88.5 to 90.8% OM, 92.7 to 95.7% CP, and 90.2 to 92.4% for GE. Fat digestibility values reported in the previous studies (90.5 to 96.2%) were slightly lower than those in the present study (95.4 to 99.0%) (Kerr et al., 2013; Vester et al., 2010a; Vester et al., 2008). Fecal scores from those previous studies (2.2 to 3.9) were also similar to the present study (2.3 to 3.5). These consistent reports of very high macronutrient digestibility values in cats fed raw meat diets provide solid evidence of their application as dietary options for these species.
In the wild, large exotic cats obtain up to 60% of their total energy from fat in their diet and cats can digest diets with large amounts of fat (up to 67% energy as fat) (Scott, 1968). Although all diets in the present study had high fat digestibility values, the statistically higher (P<0.05) digestibility of fat detected when cats were fed the Pork or Horse diets compared to B1 and B2 may have resulted from variations in fatty acid profiles of the different protein sources.

Horsemeat has been found to be as much as 76% higher in polyunsaturated fatty acids (PUFA), as much as 12% lower in monounsaturated (MUFA), and nearly 20% lower in saturated fatty acids compared to beef and pork (He et al., 2005). He et al. (2005) also found that, compared to beef and pork, horse lipids contain 2 and 5 times more linoleic acid (C18:2) and 8 and 18 times more linolenic acid (C18:3), respectively. In that study, percent of arachidonic acid (C20:4) was not different between horse, pork, and Holstein beef. Ratios of fatty acids present in pork, beef, and horse are quite different. Ratios of palmitic (C16:0) to lauric (C12:0) acid for pork, beef, and horse are 105.41, 21.49, and 163.47, respectively and stearic (C18:0) to lauric (C12:0) acid ratios are 51.82, 17.78, and 325.60, respectively (Irina, 2011), showing that fatty acid length also differs between protein sources.

Cats have a requirement for arachidonic acid because they lack the enzyme (Δ6 desaturase) to synthesize it from linoleic acid (MacDonald et al., 1984). Because protein sources used in the current study are not significantly different in this fatty acid, this is unlikely to be the cause of differences in fat digestibility. Horsemeat being much higher in linoleic and linolenic acid is a potential driver of digestibility differences. Another possible explanation for the observed differences in fat digestibility is the length of fatty acids present in each protein source. In general, beef is high in medium chain fatty acids (C8 to C13) and
pork is low in long chain fatty acids (Irina, 2011). Although one study did not show differences in digestibilities of individual fatty acids of varying chain lengths when fed to domestic cats (Kane et al., 1981), this field warrants more research as the specifics of fat digestion for various types of fats (saturated, unsaturated, etc.) in cats is not well understood but this is a possible explanation for differences in utilization of dietary fat.

Regardless of protein source, all of the diets tested were highly digestible for protein. For comparison, one previous study that fed African wildcats found the digestibility of protein ranged from 80.5 and 85.7% when cats were fed poultry-based kibble and canned diets, respectively (Kerr, 2012). These reported values were lower than those in the current study and may be due to heat processing of the diets causing a chemical reaction between sugars and amino acids, known as Maillard reactions, which is favored by high temperatures (Camire et al., 1990). The reaction between sugars and amino acids, as well as cross-linkages of amino acids, may reduce amino acid retention (Björck et al., 1984) and availability as well as protein digestibility (Björck et al., 1983). Kerr (2012) also showed that the protein digestibility of whole prey (chicks) was 86.08% in African wildcats. This higher protein digestibility compared to kibble and canned diets further suggests that heat processing reduces protein digestibility.

Undigested molecules, such as proteins, reaching the large intestine serve as substrates for bacteria, which are in largest concentrations in the colon (Blaut and Clavel, 2007). With specific regard to high protein carnivore diets, protein digestibility is vital because low protein digestibility can lead to more protein reaching the large intestine where it is fermented and putrefactive components (phenol/indole) are produced which negatively impact gastrointestinal health (Vester et al., 2008). Diet influences the populations and
activity of the gut microbiota. Additionally, beneficial intestinal bacteria provide energy and help maintain the immune system, while phenols and indoles have been proposed to have carcinogenic properties (Blaut and Clavel, 2007).

Difference in protein digestibility seen in the current study may be a result of protein source. In addition to beef and meat by-products, the B2 diet used in this study contained fish meal and soybean meal as protein sources. The other diets contained no rendered meals and only consisted of muscle meat and/or raw meat by-products. Previous studies that compared the digestibility of raw versus extruded kibble diets demonstrated that processing the protein source had a large impact on digestibility. In these studies, when compared to raw meat diets, extruded diets that contained chicken meal as the first ingredient were 8.3% (Vester et al., 2010b) and 12.5% (Kerr et al., 2012) less digestible in protein when fed to African wildcats and domestic cats. Additionally, when fed to sand cats, an extruded diet containing poultry by-product meal, soybean meal, and corn gluten meal as first ingredients had 15.7% lower protein digestibility compared to a raw diet (Crissey et al., 1997). In addition to possible Maillard reactions reducing protein digestibility, diets containing meat and by-product meals may contain larger amounts of starch and lower concentrations of protein than do 100% raw meat diets, which may contribute to lower digestibility. Plant protein sources such as soybean meal are less digestible than animal tissue, as shown by the previously discussed studies. Soybean meal contains 22 to 25% neutral detergent fiber (i.e. starch/carbohydrates) (Karr-Lilienthal et al., 2004) which cats are less efficient at digesting because their natural diet does not contain large amounts of fiber or carbohydrates (McDonald, 2002). These factors may have contributed to the lower digestibility observed with the beef diet containing soybean meal and fish meal.
A cat’s diet in the wild, consisting primarily of animal tissue, contains large concentrations of protein with minimal carbohydrates. For this reason, the evolution of the cat has led to a heightened ability to utilize protein and lipid as energy sources by converting them to glucose, and a loss of the ability to utilize precursors from plants. Enzymes associated with protein digestion are elevated in cats, leading to rapid catabolism of protein and use of amino acids for gluconeogenesis (Morris, 2002). Additionally, because carbohydrates are not abundant in cat diets, many enzymes associated with carbohydrate/starch digestion, such as glucokinase (Ballard, 1965), amylase and disaccharidases (Kienzle, 1993), are absent or down-regulated in the cat leading to a decreased ability to utilize carbohydrates directly. Cats may have pathways not present in other mammals for further conversion of amino acids to glucose. For example, the ability to utilize serine in a gluconeogenic pathway without the typical enzyme needed to do so (serine dehydratase) suggests a pathway present in cats that is not seen in rats (MacDonald et al., 1984).

The digestive anatomy and metabolic pathways of cats lead them to digest and utilize dietary protein sources quite differently than other mammals. All of these factors may explain why the diet containing a plant-based protein source was less digestible than others that contained only meat-based protein. Statistically lower protein digestibility seen in the Horse diet compared to Pork and B1 may be due to lower protein (amino acid) content in horsemeat seen in this study, which also has been seen in other studies (Badiani et al., 1997). Because cats use amino acids from proteins as gluconeogenic substrates to make energy and get much of their energy from lipids, differences in fat and protein digestibility may have led to GE digestibility differences seen in the present study.
Common methods of predicting metabolizable energy (ME) values for domestic cat diets have been the use of modified Atwater factors (8.5 kcal/g fat, 3.5 kcal/g protein, 3.5 kcal/g carbohydrate) and an equation developed by the NRC to estimate ME of cat foods (ME=DE - (0.77 * g protein)) (NRC, 2006). Atwater factors are derived from energy content of nutrients as well as digestibility of a standard kibble diet. Specifically, modified Atwater factors reflect digestibilities of 85, 95, and 80% for carbohydrate, fat, and protein, respectively (Kienzle, 2002). Results from the current study show as high as 99.00 and 95.74% digestibility for fat and protein, respectively. Higher 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 that are based on digestibility of a kibble diet are used.

Modified Atwater values yield 4.56, 4.52, 4.66, and 4.86 kcal/g ME for the Pork, Horse, B1, and B2 diets, respectively. The NRC equation predicts ME values of 5.30, 5.04, 5.02, and 5.44 kcal/g, respectively, for the four diets. Using composition and digestibility of the Pork, Horse, B1, and B2 diets from the current study, digestible energies (DE) are 5.76, 5.45, 5.47, and 5.84 kcal/g, respectively. Differences of DE and ME in diets used in the current study are as high as 20.83% using Atwater factors and 8.23% using the NRC equation. Urine energy losses in domestic cats were 6.50% of energy intake in cats fed a high protein (61.5%) canned diet (mixed with beef heart) and 4.59% in cats fed a high fat diet (49.1% fat, 39.9% protein) (Riond et al., 2003). This, along with negligible gas loss because limited fermentation in cats, means that differences between DE and ME should be smaller than prediction methods project. Atwater factors and NRC equation predictors still
underestimate ME for raw meat diets and this should be considered when feeding raw meat diets.

Differences in fiber source may have been the cause for difference in fecal scores in the present study. Fiber sources included cellulose in the Horse diet, beet pulp in the B1 and B2 diets, and both beet pulp and cellulose in the Pork diet. Smaller cat species, such as cheetahs, have been shown to tolerate beet pulp as a source of fiber while larger species, such as tigers, require more cellulose to limit fermentation and maintain optimal fecal scores (Kerr, 2012). Cellulose, a non-fermentable fiber, provides the bowel with tactile stimulation which induces colonic motility and weight (Bueno et al., 2000b) while fermentable fibers, such as beet pulp, will induce chemical changes in the bowel and production of short chain fatty acids (SCFA), which 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 a stool that is looser (higher fecal score) than an animal receiving a less fermentable fiber source. This is reflected in the current study where fecal scores from cats fed B1 and B2 diets, containing beet pulp as a fiber source, were higher (P<0.05) than scores from cats fed Horse or Pork. Additionally, fecal scores from cats fed Horse, that contained cellulose, were the lowest (P<0.05) of fecal scores in the present study. It has been suggested that a complete raw diet would include a combination of 2% beet pulp and 2% cellulose 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).

Through grooming, cats ingest large amounts of their fur which is excreted and can be seen in their feces. This hair would be analyzed largely as protein because hair is
composed of up to 95% protein, largely keratin, with the rest being water and lipid (Robbins, 2012). Because ingestion of hair cannot be accurately quantified or accounted for in zoo based research, protein digestibility values may be inaccurate. Larger amounts of protein analyzed in feces (excreted) would reduce the apparent protein digestibility, meaning protein digestibility may in fact be even higher than reported. This could be corrected if an accurate assay could be applied in the zoological setting to correct the ingestion of hair or other types of animal-based components that are not digested and therefore, act as animal-based dietary fibers.

Typical fiber assays (crude and total dietary fiber) only capture plant-based fibers and were not developed to account for animal-based components that act as dietary fiber. Recently, the concept of animal fiber (hair, bones, cartilage, etc.) has received more attention. Animal fiber, in the form of whole prey reduces phenol and indole production by 65.5 and 61.4%, respectively, in cheetahs fed whole rabbits versus raw meat chunks (Depauw et al., 2013). Reduced production of phenols and indoles may indicate improved gut health because presence of phenols and indoles reduce the viability of beneficial intestinal bacteria, including lactic acid bacteria (Nowak and Libudzisz, 2006). These beneficial intestinal bacteria provide many benefits such as metabolizing fiber to produce energy and protection from harmful bacteria that may act as carcinogens. Additionally, fiber can function as a pre-biotic, appetite regulator, and produce valuable short-chain fatty acids that provide energy for the large intestine (Fahey et al., 2003). As mentioned previously, protein digestibility of whole prey (chicks) also has been shown to be more than 6.5% higher than an extruded diet fed to African wildcats (Kerr, 2012). This further suggests the intestinal benefit of animal fiber. An assay analyzing for animal fiber specifically would more
accurately reflect the fiber present in hair and raw carnivore diets and should be researched further particularly for application in carnivore diets.

A period effect was detected during statistical evaluation regarding, DM (P=0.0012), OM (P=0.0064), and GE (P=0.0075) digestibility values. Period 3 values were 3.71 to 5.11, 2.54 to 3.32, and 2.10 to 2.85% lower for DM, OM, and GE digestibility, respectively, compare to periods 1, 2, and 4. The reason for this is not clear, but temperature was ruled out because average temperatures (12.78, 18.89, 18.89, 23.89°C for period 1 through 4, respectively) for period 3 were not higher than other periods. Possible explanations for this may be slightly higher average rainfall during this period (3.68 inches in period 3 compared to 2.30, 0.94, and 1.96 in periods 1, 2, and 4, respectively) or visitor presence. Period 3 took place during late May to early June, the period of time when visitor attendance begins to increase. Attendance records for Omaha’s Henry Doorly Zoo & Aquarium show that, for the four periods this study took place, period 3 had the most total visitors. Visitor attendance for period 3 (129,693) was as much as 40% higher compared to periods 1 (77,765), 2 (97,027), and 4 (108,774). It is possible that cats are affected by this increased commotion and traffic. This should be accounted for and investigated in future research.

**Experiment 2- Palatability**

The objective of the palatability experiment was to determine if cats would willingly consume the pork-based diet. The purpose was not to determine if there was a preference for the pork diet over the typical beef diet. Although data from this study were not statistically analyzed, numerically large cats offered pork chose to consume it more than 50% of the time. This information is valuable because many cats refuse to eat certain diets, for various
reasons. Testing the palatability of a new diet in several individuals of multiple species shows that cats, on average, will likely accept this novel protein-based diet.

Acceptance of a new diet is important from a managerial as well as nutritional perspective. If adding dietary variety is a goal of zoo management, the diets that are offered must be palatable to those animals. Variety without palatability is counterproductive and may lead to more diet refusals and possibly nutritional deficiencies. If diet palatability has been tested prior to purchasing and offering a diet, less effort and money will be spent finding diets that animals will consume. From this perspective, palatability is equally as important as nutritional adequacy and digestibility. Likewise, it is essential to recognize that cats having little exposure to varied diets will not necessarily readily consume a new option. This should be considered during initial palatability experimentation because a single offering is not likely representative of cat acceptance long-term. The cats in the present study were routinely offered a variety of meats and whole prey; therefore, they may have accepted the pork diet more readily than counterparts managed at institutions providing little to no dietary variety in the nutrition routine.

Conclusions

Raw pork-based diets have not been evaluated for digestibility in exotic felids prior to this study. Numerically, the pork diet was the most digestible for every macronutrient analyzed, with the exception of fat. Additionally, on average, cats consuming the pork diet had fecal scores that were closest to ideal (considered 3.0). This further suggests that cats utilized the pork diet well and that it supported overall gut health in the animals studied.

The pork-based diet used in this study was similar to standard commercially processed raw meat diets in macronutrient and energy composition. Although some
macronutrient and energy digestibility values, as well as fecal scores, differed statistically, all diets were well digested by study subjects. Large exotic felids also will choose to consume the pork diet and do not show obvious aversion to it. In conclusion, a raw pork-based diet containing pork by-products can be included as a dietary option for various exotic felid species managed in zoological institutions. Further research should be conducted to evaluate application for other managed carnivorous species including birds of prey and canids.

Literature Cited


Kerr, K., 2012, Nutritional evaluation of raw meat and whole prey diets for domestic and exotic cats (Doctoral Dissertation), University of Illinois at Urbana-Champaign.


NPB, 1999, Case studies of value added pork production & marketing, National Pork Board.


SDSU, 2015, Swine grading, Brookings, SD, South Dakota State University.


SSR, 2014, Unpublished, Sustainable Swine Resources.


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 Biology, v. 27, p. 126-36.


Tables

Table 3.1. Chemical composition of pork-, horse-, and beef-based raw meat diets fed to captive large exotic felids (DM basis)\(^1\,\,^2\)

<table>
<thead>
<tr>
<th>Item</th>
<th>Pork</th>
<th>Horse</th>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>31.65</td>
<td>35.64</td>
<td>32.80</td>
<td>32.23</td>
</tr>
<tr>
<td>OM, %</td>
<td>94.56</td>
<td>92.28</td>
<td>91.95</td>
<td>93.11</td>
</tr>
<tr>
<td>CP, %</td>
<td>58.54</td>
<td>53.25</td>
<td>58.02</td>
<td>51.86</td>
</tr>
<tr>
<td>Fat, %</td>
<td>28.95</td>
<td>30.99</td>
<td>30.97</td>
<td>35.81</td>
</tr>
<tr>
<td>CF, %</td>
<td>2.44</td>
<td>3.09</td>
<td>3.47</td>
<td>2.31</td>
</tr>
<tr>
<td>TDF, %</td>
<td>5.63</td>
<td>7.34</td>
<td>7.90</td>
<td>5.54</td>
</tr>
<tr>
<td>GE, Kcal/g</td>
<td>6.23</td>
<td>5.97</td>
<td>6.06</td>
<td>6.43</td>
</tr>
</tbody>
</table>

\(^1\) Abbreviations used: DM, Dry Matter; OM, Organic Matter; CP, Crude Protein; CF, crude fiber; TDF, total dietary fiber; GE, Gross Energy

\(^2\) B1=Beef diet 1; B2=Beef diet 2
### Table 3.2. Ingredient composition of a pork-, horse-, and beef-based raw meat diet fed to captive large exotic felids

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ingredient Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pork</td>
<td>Pork, pork by-products, vitamins (beet pulp, cellulose, calcium carbonate, rice hulls, sodium chloride, mineral oil, vitamin E supplement, d-alpha-tocopheryl acetate (source of natural vitamin E), biotin, niacin supplement, thiamine mononitrate, vitamin B12 supplement, vitamin A acetate, vitamin D3 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)</td>
</tr>
<tr>
<td>Sustainable Swine Resources, LLC; Carnivore Essentials</td>
<td>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 D3 supplement), trace mineral premix (copper sulfate, manganese sulfate, ethylenediamine dihydriodide, sodium selenite), choline chloride, taurine, salt</td>
</tr>
<tr>
<td>Horse</td>
<td>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 D3 supplement, menadione dimethyl-pyrimidinol bisulfate, riboflavin, pyridoxine hydrochloride, thiamin mononitrate, manganese sulfate, d-calcium pantothenate, folic acid, ethylenediamine dihydriodide, calcium iodate, sodium selenite</td>
</tr>
<tr>
<td>B1</td>
<td>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, manganese oxide, copper oxide, mineral oil, sodium selenite, calcium iodate)</td>
</tr>
<tr>
<td>B2</td>
<td>Nebraska-Brand®; Special Beef Feline, Nebraska Packing Inc., North Platte, NE</td>
</tr>
</tbody>
</table>
Table 3.3. Intake, fecal output, fecal characteristics, and apparent total tract macronutrient digestibility in captive large exotic felids (n=10) fed pork-, horse-, and beef-based raw meat diets.1,2

<table>
<thead>
<tr>
<th>Item</th>
<th>Diet</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pork</td>
<td>Horse</td>
<td>B1</td>
<td>B2</td>
<td>SEM</td>
</tr>
<tr>
<td>Intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Food intake, g DM/d</td>
<td>570.03</td>
<td>612.34</td>
<td>546.49</td>
<td>596.01</td>
<td>128.38</td>
</tr>
<tr>
<td>GE intake, kcal/d</td>
<td>3556.45</td>
<td>3674.62</td>
<td>3292.61</td>
<td>3804.60</td>
<td>798.11</td>
</tr>
<tr>
<td>Fecal Output</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fecal output, g as-is/d</td>
<td>264.92b,c</td>
<td>232.07b</td>
<td>301.26a,c</td>
<td>343.06a</td>
<td>76.76</td>
</tr>
<tr>
<td>Fecal output, g DM/d</td>
<td>69.02a</td>
<td>98.60b</td>
<td>79.08a,b</td>
<td>87.26a,b</td>
<td>20.27</td>
</tr>
<tr>
<td>Fecal Scores</td>
<td>2.94b</td>
<td>2.30c</td>
<td>3.42a</td>
<td>3.54a</td>
<td>0.21</td>
</tr>
<tr>
<td>Apparent Digestibilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DM, %</td>
<td>87.97a</td>
<td>83.59b</td>
<td>86.12a,c</td>
<td>85.60b,c</td>
<td>1.14</td>
</tr>
<tr>
<td>OM, %</td>
<td>90.76a</td>
<td>88.53b</td>
<td>89.22a,b</td>
<td>89.17a,b</td>
<td>0.91</td>
</tr>
<tr>
<td>CP, %</td>
<td>95.74a</td>
<td>92.71b</td>
<td>95.23a</td>
<td>93.14b</td>
<td>1.02</td>
</tr>
<tr>
<td>Fat, %</td>
<td>98.51a</td>
<td>99.00a</td>
<td>95.41b</td>
<td>96.45b</td>
<td>0.85</td>
</tr>
<tr>
<td>GE, %</td>
<td>92.38a</td>
<td>91.29a,b</td>
<td>90.21b</td>
<td>90.85a,b</td>
<td>0.79</td>
</tr>
<tr>
<td>Digestible Energy, kcal/g</td>
<td>5.76</td>
<td>5.45</td>
<td>5.47</td>
<td>5.84</td>
<td></td>
</tr>
<tr>
<td>ME, kcal/d3, kcal/g</td>
<td>4.56</td>
<td>4.52</td>
<td>4.66</td>
<td>4.86</td>
<td></td>
</tr>
<tr>
<td>ME, kcal/d4, kcal/g</td>
<td>5.30</td>
<td>5.04</td>
<td>5.02</td>
<td>5.44</td>
<td></td>
</tr>
</tbody>
</table>

Means within a row lacking a common superscript letter are different (P<0.05).
1 Abbreviations used: DM, dry matter; OM, organic matter; CP, crude protein; GE, gross energy.
2 B1=Beef diet 1; B2=Beef diet 2
3 ME = 8.5 kcal of ME/g of fat + 3.5 kcal of ME/g of CP + 3.5 kcal of ME/g of N-free extract
4 ME = DE – (0.77 * g protein of diet)
Figure 3.1. Descriptive percentage of large exotic cats (*Panthera tigris tigris* (n=1), *Puma concolor* (n=1), *Panthera leo* (n=1), *Acinonyx jubatus* (n=1), *Panthera onca* (n=2)) that (A) first approached and (B) first tasted a beef- and pork-based raw meat diet when diets were simultaneously presented in a two-bowl preference test.
CHAPTER 4

INFLUENCE OF PORK AND PORK BY-PRODUCTS ON MACRONUTRIENT, ENERGY DIGESTIBILITY IN SMALL CAPTIVE FELIDS AND MICROBIAL POPULATION EVALUATION IN RAW MEAT DIETS

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*Department of Animal Sciences, Iowa State University, Ames, IA
†Omaha Henry Doorly Zoo & Aquarium, Omaha, NE

Abstract

Raw meat diets are more digestible than canned or kibble diets in domestic cats, but there is a paucity of this research in small exotic felids. Additionally, only two raw meat protein sources (beef or horse) are currently commercially available for carnivores managed in zoological institutions. Adding another protein source, such as pork, has the potential to mitigate several gastrointestinal issues. Concerns with high levels of microbial populations in raw meat and associated diseases have also been expressed. The objectives of this study were to determine if a pork-based diet had similar apparent total tract macronutrient and energy digestibility and fecal scores as standard zoological carnivore diets formulated with either horse or beef, in small exotic felids, and evaluate microbial populations in the raw diets. Dietary treatments consisted of four raw meat-based diets: horse, beef, beef/horse blend, and pork. All diets were highly digestible, especially fat digestibility (98.58 to 99.73%) in which there were no statistical differences between diets. Digestibility of organic matter (OM) was higher (P<0.05) when cats consumed the Blend diet (97.15%) compared to the Pork diet (93.10%). Fecal scores ranged from 1.55 to 2.63, with Beef (2.63) being statistically higher (P<0.05) than Horse (1.55) and Pork (1.91). Microbial counts were variable in diets (E. coli: 110 to 10,000 cfu/g; total coliforms: 150 to 28,000 cfu/g; yeast: 20 to 4,000 cfu/g; mold
count: not detectable to 10 cfu/g; aerobic plate count: 23,000 to 26,000,000 cfu/g).

Staphylococcus aureus was not detected in any of the diets. *Salmonella* was presumptive positive in the Pork and Blend diet, and was negative in the other two diets. In conclusion, a pork-based diet is well utilized by exotic small cats and can be included among dietary options.

Key words: raw, zoo, pathogen, exotic, cats, novel

Introduction

Raw meat diets have not been adequately evaluated in small cat species. Conducted studies using African wildcats (*Felis silvestris lybica*) or domestic cats (*Felis catus*) have shown that canned diets may be approximately 6.7 (organic matter (OM)) to 19.6% (dry matter (DM)) less digestible than raw meat diets (Kendall et al., 1982; Kerr, 2012). Fat digestibility of a kibble diet fed to domestic cats also has been shown to be 4.4 to 41.3% less digestible than raw meat diets (Kendall et al., 1982; Kerr et al., 2012). Kerr et al. (2012) further showed that cooking a raw diet resulted in small numerical reductions in dry matter (DM), organic matter (OM), crude protein (CP), fat, and gross energy (GE) digestibility, with the largest reduction observed for DM digestibility (3.3%). Previous studies involving exotic small cat species African wildcats (*Felis silvestris lybica*) or sand cats (*Felis margarita*) also have shown reductions in macronutrient digestibility, specifically reductions of 8.3 to 15.7% CP digestibility when cats were fed kibble diets compared with raw (Crissey et al., 1997; Vester et al., 2010b).

Small exotic cat species managed in captivity are typically fed kibble, canned, raw meat, whole prey, or combinations of those diet types. Currently, there are two major protein sources available as commercial raw diet formulations designed for exotic felids, beef or
horse. A pork-based diet has typically not been fed and has not been evaluated in felids. Reluctance to feed a raw pork-based diet may be due to specific pathogenic concerns associated with pork. *Trichinella*, a parasitic nematode that resides in and is consumed through muscle meat (Catty, 1969), pseudorabies (Aujeszky’s disease), a herpesvirus (Nauwynck et al., 2007), and *Toxoplasma*, a protozoa that can reside in any edible part of an infected animal (Hill and Dubey, 2002), have all been directly associated with raw pork in the past. Additionally, pathogenic *Salmonella* and *Escherichia coli* (E. coli) contamination, are also of concern when feeding any raw meat diet to animals.

Some manufacturers of commercially produced raw meat diets may utilize interventions to mitigate microbial concerns. Interventions include high pressure pasteurization (HPP) that uses high pressure and low heat (Rastogi et al., 2007) to destroy pathogens. Additionally, irradiation which uses ionizing radiation (Farkas, 1998), and organic acids that destroy microbes and pathogens through biological end products or pH changes (Hwang and Beuchat, 1995) also aid in reducing microbial concerns. In addition to microbial interventions, freezing of raw meat products destroys some parasites and improved farm practices (no garbage feeding and improved sanitation) have helped reduce presence of some parasites of concern, including *Trichinella* (Greve, 2012) and *Toxoplasma* (Lindsay et al., 2012) while vaccination of pigs manages pseudorabies (Thiry et al., 2013). *Trichinella* was once a major concern of the pork industry, but from 1947 to 1951 the median number of reported human *Trichinellosis* cases was 393 and between 2002 and 2007 only 66 cases were reported, of which only 7 were associated with commercial pork consumption (Kennedy et al., 2009). Similarly, through vaccination and eradication programs, all 50 U.S. states were deemed pseudorabies free in 2004 (USDA, 2008). Furthermore, proper storage, thawing,
handling, feeding, and sanitation, as outlined by the United States Department of Agriculture (USDA) can reduce the microbial risk associated with raw meat diets (Crissey et al., 2001).

While the USDA has published a document outlining proper handling and storage of raw meat to control microorganism growth and contamination (Crissey et al., 2001), there are no published regulations or recommendations for allowable microbial loads in raw carnivore diets. The European Commission (EC) has set regulations on the limit of microorganisms in meat products sold for human consumption. *Salmonella* must be absent in 10 grams of product, E. coli must be below 500 cfu/g, and aerobic colony count must be less than $5 \times 10^6$ cfu/g (EC, 2005). The ability of cats to remain asymptomatic after consuming raw meat contaminated with *Salmonella* (Carter and Quinn, 2000; Finley et al., 2006) suggests they tolerate high numbers of microorganisms in their food, compared to humans. Furthermore, *Salmonella* species have been isolated from the feces of up to 36 and 18% of clinically healthy domestic dogs and cats, respectively (Sanchez et al., 2002). Fecal shedding of *Salmonella* also has been looked at in exotic felids. One study documented 95% of felids (including snow leopards (*Panthera uncia*), leopards (*Panthera pardus*), cougars (*Felis concolor*), caracals (*Felis caracul*), and servals (*Felis serval*) from a private collection and 94% of felids (including tigers (*Panthera tigris*), Asian lions (*Panthera leo persica*), African lions (*Panthera leo*), snow leopards, cheetahs (*Acinonyx jubatus*), cougars, and a Canadian lynx (*Lynx canadensis*) from a zoo collection tested positive for *Salmonella*, with no clinical symptoms or signs of illness (Clyde et al., 1997). Therefore, it is likely that, a majority of the time, carnivores are not clinically affected by the presence of pathogens such as *Salmonella* and regulations set for human grade meat products are unnecessary and too strict when it comes to raw carnivore diets.
The objective of this study was to determine if a pork-based diet has the same apparent total tract macronutrient digestibility and fecal scores as standard zoological carnivore diets formulated with either horse or beef, in small captive exotic felids. Additionally, the microbial populations in dietary treatments were evaluated. We hypothesized that a pork-based diet would be as digestible as typical beef or horse-based raw meat diets, and could be included among dietary options for captive small exotic felids. We also hypothesized that microbial loads would be variable among diets but would not affect cats clinically.

Materials and Methods

Animals

Four African wildcats (Felis silvestris lybica) (2 males, 2 females, average age 9.5 years, average weight 4.75 kg) were used, all of which had received a dry kibble diet prior to this study. Cats were individually housed in enclosures of, on average, 9.16 m³ at Lee G. Simmons Conservation Park and Wildlife Safari and cared for by park staff. Water was provided ad libitum throughout the study. All animal procedures were approved by the Lee G. Simmons Conservation Park and Wildlife Safari (WSP) Animal Care and Use Committee (IACUC) before animal experimentation.

Diet Composition and Microbes

Four commercially produced raw meat-based diets formulated to meet or exceed nutrient requirements for cats (NRC, 2006) were purchased and used in the study. Chemical compositions of diets are included in Table 4.1. Dietary treatments included a horse-based (Nebraska Brand®, North Platte, NE, USA: Premium Feline Diet (Horse)), beef-based (Nebraska Brand®, North Platte, NE, USA: Special Beef Feline Diet (Beef)), beef and horse-
based blend (Triple A Brand Meat Company®, Burlington, CO, USA: Complete Feline Diet (Blend)) and pork-based (Sustainable Swine Resources, LLC, Sheboygan Falls, WI, USA: Carnivore Essentials (Pork). Each dietary treatment was subsampled, dried at 55°C, ground through a 2-mm screen (Wiley mill, model 3383-L10, Thomas Scientific, Swedesboro, NJ) and analyzed for chemical composition. Dietary treatments were analyzed for dry matter (DM) (Method 934.01) and organic matter [OM (Method 942.05) AOAC, 2006]. Crude protein (CP) was determined using a Leco Nitrogen/Protein Determinator (Method 992.15) (model FP-528, Leco Corporation, St. Joseph, MI). Fat concentrations were determined by hexane extraction (Method 991.36) AOAC, 1995). Gross energy (GE) was determined by bomb calorimetry (model AC 500, Leco Corporation, St. Joseph, MI). Crude fiber (CF) was analyzed by Midwest Laboratories [Omaha, NE] (AOCS Ba6a-05 (Thiex, 2008)]. Total dietary fiber (TDF) was also determined (Prosky et al., 1994) using triple the amount of protease and double the time for the water bath after addition of the protease, for a high protein sample. Microbial evaluations of raw meat diets were conducted at Midwest Laboratories [Omaha, NE] (Method 991.14) AOAC, 1994); (Method 2003.07) AOAC, 2003); (FDA/BAM, 2001b); (FDA/BAM, 2001a)]. All chemical analyses were conducted in the nutrition lab at Omaha’s Henry Doorly Zoo and Aquarium (Omaha, NE) unless otherwise noted.

**Experimental Design**

The experimental design was a 4x4 Latin square with animals being randomly assigned to one of four dietary treatments. Animals were fed each diet treatment isocalorically to the animal’s caloric intake to maintain body weight as determined prior to beginning of research. Each treatment period consisted of ten days for diet adaptation.
followed by four days of sample collection. During each day of the collection periods, total food intake and fecal output as well as fecal scores were measured for each individual. Feces were evaluated using a scale of 1 to 5 with: 1=hard, dry pellets; 2=dry, well-formed; 3=soft, moist, formed; 4=soft, unformed; 5=watery liquid (Felid TAG, 2014).

**Energy and Macronutrient Digestibilities**

Total fecal samples for each cat were pooled for each collection period and dried at 55°C and ground through a 2-mm screen (Wiley mill, model 3383-L10, Thomas Scientific, Swedesboro, NJ). All fecal samples were analyzed for DM, OM, CP, GE, and fat concentrations using methods previously described for diet analyses. Apparent total tract digestibility values were calculated using the equation as follows: ((nutrient intake - fecal output) / (nutrient intake)) * 100. Digestible energy values were calculated using the following equation: (kcal/g energy in diet * energy digestibility of respective diet). Metabolizable energy (ME) of diets were calculated using modified Atwater values (8.5 kcal/g fat, 3.5 kcal/g protein, 3.5 kcal/g carbohydrate) multiplied by fat, protein, and carbohydrate content of each diet. Carbohydrate content of diets was calculated by finding nitrogen free extract (NFE) in the following equation: (100-(%ash+%CP+%fat+%TDF)). Due to assay error (likely TDF) NFE of some diets was a negative number, in which case a value of zero was used for NFE. ME was also calculated using the NRC equation: (ME=DE-(0.77 * g protein in diet)) (NRC, 2006).

**Statistical Analysis**

All data were analyzed using the Mixed Model procedure of SAS® (SAS Institute, Cary, NC). The fixed effect of diet was tested and cat 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®. One cat was dropped from the study halfway through period 2 because of lack of intake (less than 30% for three consecutive days), when fed the Blend diet. The cat was put back on the study for period 3 and resumed eating, when receiving the Pork diet. The same cat was again dropped from the study in period 4 because of lack of consumption, when fed the Horse diet. Data from the cat dropped from period 2 and 4 was not included in statistical analysis for those periods, but was included for periods 1 and 3. Fat digestibility for that cat was not included in periods 1 and 3, because of lack of sample for analysis.

Results

Diet Composition

Ingredient lists for all dietary treatments can be found in Table 4.2. Diet composition between all diets was similar for OM (90.44 to 93.95%) and GE (6.09 to 6.72 Kcal/g) composition, but was variable in other nutrients. The Blend diet had the lowest DM (28.74%) and fat (25.40%) concentrations and highest CP (65.70%) concentrations. The other diets (Horse, Beef, and Pork) ranged in DM from 32.96 to 36.92% and CP from 50.34 to 52.36%. The Pork diet was highest in fat concentration (39.91%) compared to other diets. Fiber (CF and TDF) was highly variable among diets with lowest values for both in the Blend diet (1.17 and 1.15%, respectively) and highest in the Horse diet (3.09 and 7.34%, respectively) (Table 4.1).

Diet Microbes

Microbial counts were variable between diets and can be found in Table 4.3. E. coli, total coliform, and mold counts were highest in the Beef diet (10,000; 28,000; and 10 cfu/g,
respectively). Yeast and aerobic plate counts were highest in the Blend diet (4,000 and 26,000,000 cfu/g, respectively). Staphylococcus aureus was not detected in any of the diets (10 cfu/g reporting limit). Salmonella was presumptive positive in the Pork and Blend diet, and was negative in the other two diets.

**Energy and Macronutrient Digestibilities**

Diet intakes and fecal output and characteristics can be found in Table 4.4. Dry matter intakes (g/day) of all diets were not statistically different, but GE intake (kcal/d) was lowest (P<0.05) for Horse (548.12 kcal). GE intake for the Blend diet (1,095.55 kcal) was also higher (P<0.05) than Pork (834.25 kcal). With the exception of the cat removed from the study on two periods, all cats maintained body weight within 5% during the course of this study. Fecal dry matter outputs (g/day) were not different among diets but as-is grams of fecal output (g/day) was higher (P<0.05) in animals fed Beef (15.28 g) compared to those fed the Blend diet (4.07 g). Fecal scores ranged from 1.55 to 2.63, with Beef being statistically higher (P<0.05) than Horse and Pork.

All diets were highly digestible, especially regarding fat (98.58 to 99.73%) in which there were no statistical differences between diets. Most statistical differences were seen between the Blend, Horse, and Beef diets. The Blend diet was more digestible (P<0.05) in DM (94.13%) than Horse (87.55%), more digestible (P<0.05) in CP than Beef (98.08 and 93.44% for Blend and Beef, respectively), and more digestible (P<0.05) in OM (97.15, 91.10, and 92.23% for Blend, Horse, and Beef, respectively) and GE (97.28, 92.06, and 93.33% for Blend, Horse, and Beef, respectively) than both Horse and Beef. Digestibility of OM was the only statistically significant difference detected between the Pork diet (93.10%) and the Blend diet (97.15%). No other differences in nutrient digestibility were detected for
the Pork diet compared with the other diets. Using energy digestibility values from the current study, digestible energy (DE) values for Horse, Beef, Pork, and Blend diets were 5.61, 5.89, 6.35, and 5.95 kcal/g, respectively. Modified Atwater factors yield ME predictions of 4.49, 4.66, 5.18, and 4.66 kcal/g, respectively, and the NRC equation predicts ME of 5.22, 5.49, 5.96, and 5.45 kcal/g for the Horse, Beef, Pork, and Blend diets, respectively (Table 4.4).

Discussion

Our objectives were to determine if a new commercial pork-based diet had similar apparent total tract macronutrient and energy digestibility and fecal scores as standard zoological raw carnivore diets, formulated with either horse or beef, in small exotic felids using African wildcats as a model for other exotic small cat species, and to evaluate microbial populations in the raw diets. A variety of ages 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 age affects was not an intention of this study. With regard to sex, significant digestive difference between sexes are not typically seen (Vester et al., 2008; Wynne, 1989).

Raw meat diets have not been adequately studied in felids, and a pork-based raw meat diet has not been investigated to the author’s knowledge. Adding a dietary option would be desirable because a novel protein source could add variety and potentially help combat gastrointestinal issues such as colitis, IBS, and other food sensitivities. Cases of food sensitivities have increased over the past several decades, and protein ingredients may play a role as allergens or triggers of sensitivities (Gaschen and Merchant, 2011; Guilford et al., 2001; Wills and Harvey, 1994). Novel proteins, to which an animal has no previous
exposure, can mitigate food sensitivities (Carlotti et al., 1990) as well as gastrointestinal issues such as colitis and irritable bowel syndrome (IBS) (Simpson, 1998; Verlinden et al., 2006). Pork may serve as a valuable novel protein source and use of a pork-based raw meat diet should be evaluated in animals displaying signs of food sensitivities.

Prior to the study, all cats received a kibble diet. Three of the four cats transitioned from a kibble to raw diets quickly. The fourth cat consumed less than 30% of the Blend and Horse diets, which may have been due to failure to successfully transition. While dry matter intake of dietary treatments did not differ statistically, a large standard error (11.16) may indicate a wide and variable range of intakes (35.28 to 50.74 g/d) across cats. Lack of consumption on the Blend and Horse diets shown by one cat could have been due to the novelty of the raw meat diet since a kibble diet had been previously fed. This is characteristic of cats who have been fed one diet or diet type for a majority of their lives and an aversion to other foods, termed neophobia, is common in cats (Bradshaw, 2006). Another explanation could be preference of protein source. This cat had adequate consumption (more than 30%) on the Beef and Pork diets, but not the Horse or Blend diet. It is possible that the Horse and Blend diets were not palatable to this particular cat as both diets contained a similar protein source, horsemeat.

Several factors can influence palatability of a diet. Fatty acids present in animal fat and muscle meat are largely long chain fatty acids (16 to 22 carbons) and can be saturated, unsaturated, and polyunsaturated (Wood et al., 2004). Animal lipids such as these improve palatability of diets for cats (MacDonald et al., 1984) but cats will reject foods containing large amounts of medium chain fatty acids (8:0) but not short chain fatty acids (MacDonald et al., 1985). More than lipid composition, amino acid composition can influence cat
perception of palatability. Amino acids such as proline, cysteine, ornithine, lysine, histidine, and alanine are preferred by cats while arginine, isoleucine, phenylalanine and tryptophan are less preferred (Boudreau and White, 1978; Zaghini and Biagi, 2005). Differences in intake and palatability of various meats seen with the current study may be due to differences in fatty acid or amino acid profiles of the dietary treatments and should be evaluated among exotic felid species.

**Diet Composition**

Dietary treatments were largely composed of raw meat or raw animal by-products and macronutrient compositions for all dietary treatments met domestic cat NRC requirements (NRC, 2006). All diets fed in the current study contained similar DM (28.74 to 36.92%), OM (90.44 to 93.95%), and CP (50.34 to 65.70%) concentrations as reported in previous studies analyzing raw meat diets (29.0 to 38.2% DM, 91.5 to 94.6% OM, and 44.9 to 64.5% CP) (Crissey et al., 1997; Kerr et al., 2013; Vester et al., 2010a; Vester et al., 2008). From these previous studies, fat (22.2 to 36.9%) and GE (5.9 to 6.4 kcal/g) concentrations also were similar to the current study that contained 25.40 to 39.91% fat and 6.09 to 6.72 Kcal/g GE, with the exception of the Pork diet that was slightly higher in fat and GE (39.91% and 6.72 kcal/g GE, respectively). In those that reported it (Kerr et al., 2013; Vester et al., 2008), TDF concentrations were similar in previous studies (4.8 to 8.4%) compared to the current study (1.15 to 7.34%), with the exception of the Blend diet having less TDF (1.15%). This is likely due to the fact that, while the Horse (cellulose), Beef (beet pulp), and Pork (cellulose and beet pulp) diets all contain added fiber sources, the Blend diet does not list a fiber source in its ingredient list.
Diet Microbes

Microbial analysis was performed at Midwest Laboratories, Inc. and a result of “presumptive positive” or “negative” appears on the report of analysis. Presumptive positive for *Salmonella* indicates presence of any of the more than 2,400 serotypes (Carlson et al., 2012) of *Salmonella* species, only a handful of which are truly pathogenic. Similarly, E. coli counts include all species, including more than 50,000 serotypes, of which very few are pathogenic (Orskov and Orskov, 1992). For this reason, high levels of cfu for E. coli and presumptive positive *Salmonella* results do not inherently mean a diet is dangerous to a carnivore or shouldn’t be fed. Microbes and bacteria have been an area of concern when feeding raw meat diets to animals. Felids, however, appear to be able to handle high microbial loads without negative effects on health as indicated by high nutrient digestibility and very good fecal scores. This is likely a result of a short intestinal track, with ratio of body length to intestine length around 1:4 (pigs have 1:14, goats have 1:27) (Kararli, 1995), and fast transit time, ranging from approximately 26 to 36 hours (Peachey et al., 2000), limiting opportunities for pathogens to colonize in cats. Clinical symptoms (vomiting, diarrhea, lethargy, lack of diet consumption, lameness) and disease related to pathogenic microbes in diets were not observed or reported in the cats fed any of the diets tested during this study. Although not evaluated in this study, influence of raw meat diets on fecal shedding of *Salmonella* should be investigated in future research.

Currently there are no guidelines or recommendations for microbial load allowable in raw meat diets fed to carnivores. Aerobic colony counts and E. coli counts in diets used in this study are five times and twenty times higher, respectively, than the allowable level the European Commission has issued for human grade raw meat products. Additionally,
Salmonella was detected in two of the four diets used in the current study, which is not allowed by the European Commission regulations. Our data support that felids can digest diets containing these very high and variable levels of microorganisms without compromising health, indicated by high nutrient digestibility and healthy fecal scores. Furthermore, if basing recommendations for felid diets from human grade regulations, guidelines should be less strict and allow a higher microbial level to match the natural history of cats. Higher allowable microbial levels in these diets may pose potential risk to humans through preparation and handling of raw meat diets. However, following USDA standard operating procedures for handling raw meat fed to exotic animals (prompt freezing at or below -18°C, thawing in refrigerated units, not re-freezing, and proper sanitation of items used in diet preparation (including hands)), should curtail these threats (Crissey et al., 2001).

**Energy and Macronutrient Digestibilities**

Overall, all diets were highly digestible, regardless of protein source. Values reported in the current study were similar to those previously reported in studies analyzing raw meat diets (horse or beef) in small exotic cat species. Previous studies reported similar ranges of OM (87.4 to 96.5%), CP (91.7 to 97.2%), fat (90.5 to 97.2%), and GE (89.6 to 97.3%) digestibility values (Crissey et al., 1997; Kerr et al., 2013; Vester et al., 2010a; Vester et al., 2008; Vester et al., 2010b). Fecal scores across treatments in the current study (1.55 to 2.63) were similar to those reported in previous studies that ranged from 1.2 to 3.3. However, compared to the current study, DM digestibility values (83.5 to 90.0%) reported in the previous studies were slightly lower than those observed in the present study (87.55 to 94.13%).
In the current study, CP digestibility of the Beef diet (93.44%) was lower (P<0.05) than the Horse (96.80%) and Blend (98.08%) diets. Protein digestibility is affected by dietary fiber. Protein digestibility of a raw meat diet was reduced by as much as 18.92% with the addition of horn meal as a fiber source (Kienzle et al., 1991). Protein digestibility reductions may be more extreme with the addition of beet pulp than with addition of cellulose. When adding different fiber sources to a basal diet to achieve approximately 9.5% TDF, protein digestibility of a raw meat diet containing beet pulp was approximately 5.77% lower than digestibility of protein when cellulose was the fiber source in diets fed to 30 domestic cats (Sunvold et al., 1995). This is likely due to beet pulp being highly fermentable (compared to cellulose) in the large intestine, and consequentially an increase in bacterial protein, leading to more protein excretion and underestimation of apparent total tract protein digestibility (Kerr, 2012). This is supported in the current study by the Beef diet, which contained beet pulp, having lower protein digestibility than Horse or Blend diets, which contained cellulose or no fiber source, respectively.

Through grooming, cats ingest large amounts of their fur which is excreted and can be seen in their feces. This hair would be analyzed largely as protein because hair is composed of approximately 95% protein, largely keratin, with the rest being water and lipid (Robbins, 2012). Because ingestion of hair could not be accurately quantified or accounted for, protein digestibility values could be inaccurate as more nitrogen would be accounted for in the feces. Larger amounts of protein analyzed in feces (excreted) would reduce the apparent protein digestibility, meaning CP digestibility values may actually be higher than reported in the current study. Hair is assumed to be largely undigested as visibly seen in
feces, therefore, could be considered “animal fiber”. This could be corrected for if a fiber assay accurately detected animal fiber rather than plant-based fibers.

Typical fiber assays (crude and total dietary fiber) currently only capture plant-based fibers and were not developed to account for animal-based components that act as dietary fiber. Recently, the concept of animal fiber (hair, bones, cartilage, etc.) has received more attention and inclusion in raw diets, in the form of whole prey, for felids has been shown to reduce phenol and indole production by 65.54 and 61.38%, respectively, in cheetahs fed whole prey versus ground raw meat diets, possibly improving gut health (Depauw et al., 2013). Additionally, fiber can function as a pre-biotic, appetite regulator, and produce valuable short-chain fatty acids that provide energy for the large intestine (Fahey et al., 2003). An assay analyzing for animal fiber specifically would more accurately reflect the fiber present in hair and fur. Evaluation of animal-based fiber in carnivore diets should be researched further.

Beyond fiber source, differences in protein digestibility could be attributed to protein sources. In addition to beef and meat by-products, the Beef diet contained fish meal and soybean meal as protein sources. The other dietary treatments contained only muscle meat and/or raw animal meat by-products. Previous studies that compared the digestibility of raw versus extruded kibble diets demonstrate that protein source has a large impact on digestibility. In these studies, when compared to raw meat diets fed to African wildcats or domestic cats, extruded diets containing chicken meal as the first ingredient were 8.3% (Vester et al., 2010b) and 12.5% (Kerr et al., 2012) less digestible in crude protein. When cats fed raw diets were compared with cats fed extruded diets containing poultry by-product meal, soybean meal, and corn gluten meal as primary ingredients, protein digestibility was
reduced by 15.7% (Crissey et al., 1997). Extruded kibble diets containing meat and by-product meal contain larger concentrations of starch and lower concentrations of protein than do raw diets, which likely leads to lower digestibility, particularly of protein in obligate carnivores. Additionally, plant-based protein sources such as soybean meal, contain as much as 18.8% nitrogen free extract (NFE) (i.e. carbohydrates) (Karr-Lilienthal et al., 2004) which cats are less efficient at digesting because they don’t have enzymes or any substantial fermentative capacity (McDonald, 2002). The heat processing to produce meal ingredients also may cause a chemical reaction between sugars and amino acids, known as Maillard reactions, which is favored by high temperatures (Camire et al., 1990). The reaction between sugars and amino acids, as well as cross-linkages of amino acids, may reduce amino acid retention (Björck et al., 1984) and availability as well as protein digestibility and quality (Björck et al., 1983).

Animal tissue, a cat’s diet in the wild, consists of large concentrations of protein with minimal carbohydrates. For this reason, the evolution of the cat has led to a heightened ability to utilize protein and lipid as energy sources by converting them to glucose and a loss of the ability to utilize precursors from plants. Enzymes associated with protein digestion are elevated in cats, leading to rapid catabolism of protein and use of amino acids for gluconeogenesis (Morris, 2002). Additionally, because carbohydrates are not abundant in cat diets, many enzymes associated with carbohydrate/starch digestion, such as glucokinase (Ballard, 1965), amylase and disaccharidases (Kienzle, 1993), are absent or down regulated in the cat leading to a decreased ability to utilize carbohydrates directly. Cats may have pathways not present in other mammals for further conversion of amino acids to glucose. For example, an ability of cats to utilize serine in a gluconeogenic pathway without the typical
enzyme needed to do so (serine dehydratase) suggests a pathway present in cats that is not seen in rats (MacDonald et al., 1984).

The digestive anatomy and biochemical pathways of cats lead them to digest and utilize dietary protein sources quite differently than other mammals. This might help explain why the Beef diet that contained a plant-based protein source had lower protein digestibility (93.44%) than the other dietary treatment (95.97 to 98.08%). Because cats use amino acids from proteins as gluconeogenic substrates to make energy and because large cats have been shown to get up to 60% of their total energy from fat in the diet (Scott, 1968), differences in fat and protein digestibility may have led to GE digestibility differences seen in the present study. For example, the Blend diet was significantly more digestible than the Beef diet in both protein and GE. The Blend diet was numerically more digestible in fat compared to the Horse diet, which may have led higher (P<0.05) GE digestibility when comparing those diets.

Common methods of predicting metabolizable energy (ME) values for domestic cat diets include the use of modified Atwater values (8.5 kcal/g fat, 3.5 kcal/g protein, 3.5 kcal/g carbohydrate) and an equation developed by the NRC to estimate ME of cat foods based on energy digestibility and protein concentration in the diet (ME=DE - (0.77 * g protein)) (NRC, 2006). Atwater factors are derived from energy content of nutrients as well as digestibility of a standard kibble diet. Specifically, modified Atwater factors reflect digestibilities of 85, 95, and 80% for carbohydrate, fat, and protein, respectively (Kienzle, 2002). Results from the current study show as high as 99.73 and 98.08% digestibility for fat and protein, respectively. Higher digestibility of raw meat diet shown in this study, and supported by those previously discussed, leads to an underestimation of ME when modified Atwater values are applied
Modified Atwater values yield 4.49, 4.66, 5.18, and 4.66 kcal/g ME, respectively, for the four diets (Horse, Beef, Pork and Blend). Applying the NRC predictive equation yields ME values of 5.22, 5.49, 5.96, and 5.45 kcal/g for the Horse, Beef, Pork, and Blend diets, respectively. Using composition and digestibility of the Horse, Beef, Pork, and Blend diets from the current study, digestible energy (DE) values were 5.61, 5.89, 6.35, and 5.95 kcal/g, respectively. Differences of DE and ME in diets used in the current study were as high as 20.68% using Modified Atwater factors and 8.40% using the NRC equation. Urine energy losses in domestic cats were 6.50% of energy intake in cats fed a high protein (61.5%) canned diet (mixed with beef heart) and 4.59% in cats fed a high fat diet (49.1% fat, 39.9% protein) (Riond et al., 2003). This, along with negligible gas loss resulting from limited fermentation in cats, means that differences between DE and ME may be smaller than prediction methods project. Modified Atwater values and the NRC equation both likely underestimate ME for raw meat diets and this should be considered when feeding raw meat diets. It is likely the NRC methodology better predicts ME of raw diets than the use of modified Atwater values.

Within the current study, mean fecal scores of cats consuming the Beef diet (2.63) were higher (P<0.05) than the Horse (1.55) and Pork (1.91) diets. Fiber sources in the dietary treatments included cellulose (Horse) beet pulp (Beef) both beet pulp and cellulose (Pork), and no added fiber ingredient in the Blend diet. These differing fiber sources may have led to differences seen in fecal scores. Smaller cat species, such as cheetahs (Acinonyx jubatus), have been shown to tolerate beet pulp (at 4% of the diet) as a source of fiber while larger species, such as tigers (Panthera tigris), require more cellulose (at 4% of the diet) to limit fermentation (Kerr, 2012). This is reflected in the Beef diet, which contained beet pulp as a
fiber source, along with a TDF concentration of 5.54%, having fecal scores closest to what is considered ideal (3.0). Cellulose, a non-fermentable fiber, provides the bowel with tactile stimulation which induces colonic motility and weight (Bueno et al., 2000b) while fermentable fibers such as beet pulp will induce chemical changes in the bowel and production of short chain fatty acids (SCFA), which can be absorbed for energy (Bueno et al., 2000a). Too much fermentable fiber, which may be around 4% for felids as suggested by Kerr (2012), in the diet may result in excess production of SCFA, increasing passive transport absorption and possibly resulting in a stool that is looser than an animal receiving a less fermentable fiber source. It has been suggested that, optimally, a complete raw diet would include a combination of 2% beet pulp and 2% cellulose to achieve optimal intestinal health (Kerr, 2012).

It has been common to conduct digestibility studies in exotic felids utilizing 10 day transition periods and 4 day collection periods. In the present study, due to very high diet digestibility, fecal samples from one cat were not sufficient to conduct all assays for chemical composition and all total fecal collections were low. For this reason, extending the collection period for small cat digestibility studies should be considered. This would allow a larger fecal sample collection and full chemical analyses.

Conclusions

When fed to cats, nutrients in a 100% pork-based raw diet were digested similar to other commercial raw carnivore diets varying in protein source. Additionally, carnivores tolerate very high and variable ranges of microbial loads in raw meat diets without impact on fecal scores or nutrient digestibility indicating guidelines for appropriate levels of microbes in carnivore diets should not necessarily follow those of human raw food. Clinical signs of
infection and disease were absent in cats fed diets containing five times the aerobic colony counts and twenty times the E. Coli counts allowable by human food standards. Cats did not show clinical signs of infection or disease, indicating that these levels, while very high, do not appear to impact felid health. All diets in the current study are acceptable based on digestibility and fecal scores, and a raw pork-based diet can be included among dietary options for captive small exotic felids.

Literature Cited


AOAC, 1995, Official method 991.36, Fat (crude) in meat, solvent extraction (Submersion) method: Official Methods of Analysis.


FDA/BAM, 2001a, Chapter 3, Aerobic Plate Count.

FDA/BAM, 2001b, Chapter 18, Yeasts, Molds and Mycotoxins.


Kerr, K., 2012, Nutritional evaluation of raw meat and whole prey diets for domestic and exotic cats (Doctoral Dissertation), University of Illinois at Urbana-Champaign.


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 Biology, v. 27, p. 126-36.


Tables

**Table 4.1.** Chemical composition of horse-, beef-, pork-, and horse/beef blend-based raw meat diets fed to captive African wildcats (DM basis)

<table>
<thead>
<tr>
<th>Item</th>
<th>Horse</th>
<th>Beef</th>
<th>Pork</th>
<th>Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>36.92</td>
<td>34.63</td>
<td>32.96</td>
<td>28.74</td>
</tr>
<tr>
<td>OM, %</td>
<td>90.44</td>
<td>91.31</td>
<td>93.95</td>
<td>91.10</td>
</tr>
<tr>
<td>CP, %</td>
<td>50.34</td>
<td>52.36</td>
<td>51.00</td>
<td>65.70</td>
</tr>
<tr>
<td>Fat, %</td>
<td>31.64</td>
<td>33.07</td>
<td>39.91</td>
<td>25.40</td>
</tr>
<tr>
<td>CF, %</td>
<td>3.09</td>
<td>2.31</td>
<td>2.44</td>
<td>1.17</td>
</tr>
<tr>
<td>TDF, %</td>
<td>7.34</td>
<td>5.54</td>
<td>5.63</td>
<td>1.15</td>
</tr>
<tr>
<td>GE, Kcal/g</td>
<td>6.09</td>
<td>6.31</td>
<td>6.72</td>
<td>6.12</td>
</tr>
</tbody>
</table>

1 Abbreviations used: DM, dry matter; OM, organic matter; CP, crude protein; CF, crude fiber; TDF, total dietary fiber; GE, gross energy
Table 4.2. Ingredient composition of horse-, beef-, pork-, and horse/beef blend-based raw meat diets fed to captive African wildcats

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ingredient Composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse (Nebraska Brand®; Premium Feline, Nebraska Packing Inc., North Platte, NE)</td>
<td>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 D3 supplement), trace mineral premix (copper sulfate, manganese sulfate, ethylenediamine dihydriodide, sodium selenite), choline chloride, taurine, salt</td>
</tr>
<tr>
<td>Beef (Nebraska-Brand®; Special Beef Feline, Nebraska Packing Inc., North Platte, NE)</td>
<td>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)</td>
</tr>
<tr>
<td>Pork (Sustainable Swine Resources, LLC; Carnivore Essentials)</td>
<td>Pork, pork by-products, vitamins (beet pulp, cellulose, calcium carbonate, rice hulls, sodium chloride, mineral oil, vitamin E supplement, d-alpha-tocopheryl acetate (source of natural vitamin E), biotin, niacin supplement, thiamine mononitrate, vitamin B12 supplement, vitamin A acetate, vitamin D3 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)</td>
</tr>
<tr>
<td>Blend (Triple A Brand Meat Company®; Feline Complete Diet, Burlington, CO)</td>
<td>Beef muscle meat, horse muscle meat, KanTech feline complete vitamin/mineral premix</td>
</tr>
</tbody>
</table>
Table 4.3. Microbial population counts of commercially available horse-, beef-, pork-, and horse/beef blend-based raw meat diets fed to captive African wildcats \(^1,2\)

<table>
<thead>
<tr>
<th>Diet</th>
<th>E. Coli (generic)</th>
<th>Total Coliforms</th>
<th>Yeast</th>
<th>Mold Count</th>
<th>Staphylococcus aureus</th>
<th>APC</th>
<th>Salmonella</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horse</td>
<td>400</td>
<td>1,000</td>
<td>480</td>
<td>n.d.</td>
<td>n.d.</td>
<td>2.3x10^4</td>
<td>Negative</td>
</tr>
<tr>
<td>Beef</td>
<td>10,000</td>
<td>28,000</td>
<td>840</td>
<td>10</td>
<td>n.d.</td>
<td>4.4x10^6</td>
<td>Negative</td>
</tr>
<tr>
<td>Pork</td>
<td>3,900</td>
<td>9,600</td>
<td>20</td>
<td>n.d.</td>
<td>n.d.</td>
<td>3.9x10^4</td>
<td>Presumptive Positive</td>
</tr>
<tr>
<td>Blend</td>
<td>110</td>
<td>150</td>
<td>4,000</td>
<td>n.d.</td>
<td>n.d.</td>
<td>2.6x10^7</td>
<td>Presumptive Positive</td>
</tr>
</tbody>
</table>

\(^1\) Reporting limits: E. Coli=10, Total Coliforms=10, Yeast=10, Mold Count=10, Staphylococcus aureus=10, Salmonella=1

\(^2\) Abbreviations used: APC, Aerobic plate count; cfu, colony-forming units, Org, organisms
Table 4.4. Intake, fecal output, fecal characteristics, and apparent total tract macronutrient digestibility in captive African wildcats fed raw meat diets

<table>
<thead>
<tr>
<th>Item</th>
<th>Diet</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Horse</td>
</tr>
<tr>
<td>Intake</td>
<td></td>
</tr>
<tr>
<td>Food intake, g DM/d</td>
<td>35.28</td>
</tr>
<tr>
<td>GE intake, kcal/d</td>
<td>548.12&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fecal Output</td>
<td></td>
</tr>
<tr>
<td>Fecal output, g as-is/d</td>
<td>8.81&lt;sup&gt;a,b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fecal output, g DM/d</td>
<td>5.36</td>
</tr>
<tr>
<td>Fecal Scores</td>
<td>1.55&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Apparent Nutrient Digestibility</td>
<td></td>
</tr>
<tr>
<td>DM, %</td>
<td>87.55&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>OM, %</td>
<td>91.10&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>CP, %</td>
<td>96.80&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Fat, %</td>
<td>98.58&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>GE, %</td>
<td>92.06&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Digestible Energy, kcal/g</td>
<td>5.61</td>
</tr>
<tr>
<td>Calculated ME, kcal/g&lt;sup&gt;2&lt;/sup&gt;</td>
<td>4.49</td>
</tr>
<tr>
<td>Calculated ME, kcal/g&lt;sup&gt;3&lt;/sup&gt;</td>
<td>5.22</td>
</tr>
</tbody>
</table>

<sup>a-c</sup> Means within a row lacking a common superscript letter are different (P<0.05)

<sup>1</sup> Abbreviations used: DM, dry matter; OM, organic matter; CP, crude protein; GE, gross energy; ME, metabolizable energy

<sup>2</sup> ME = 8.5 kcal of ME/g of fat + 3.5 kcal of ME/g of CP + 3.5 kcal of ME/g of N-free extract

<sup>3</sup> ME = DE – (0.77 * g protein of diet)
CHAPTER 5
EVALUATION OF PORK AND PORK BY-PRODUCTS AND THEIR USE AS ENVIRONMENTAL ENRICHMENT FOR CAPTIVE LARGE EXOTIC FELIDS

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Abstract

North American zoological institutions typically feed processed, soft raw meat diets. These diets are nutritionally complete, but lack physical properties of diets of wild exotic felids. Lack of mastication for consumption may contribute to behavioral and health problems. Novel objects can provide environmental enrichment to mitigate these issues. The objectives of this study were to evaluate 11 pork-based by-products for chemical and mineral composition and to determine if a pig head is biologically relevant environmental enrichment for captive large exotic felids. By-products ranged widely in composition, and ranges of macronutrient composition were: DM: 26.01-71.23%; OM: 53.04-96.79%; CP: 22.90-79.29%; fat: 22.01-63.15%; CF: 0.25-19.54%; TDF: 0.04-3.44%; GE: 3.73-7.45 kcal/gram between all 11 items. Five large exotic felids (Panthera tigris tigris, Panthera tigris altaica (n=2), Panthera tigris jacksoni, Panthera leo) were used to determine if a head would be biologically relevant environmental enrichment for large felids kept in zoos. Using instantaneous scan sampling at one min intervals, behaviors were tracked from a preset ethogram on Baseline (before head offered), Enrichment (head offered), and Post enrichment (head removed) days, over 4 weeks. Location changes, orts, fecal scores, time to approach
enrichment, and loss in head weight were also recorded. Active behaviors were 55.70% higher (P<0.0001) on Enrichment days compared to Baseline and 26.42% higher (P<0.0001) compared to Post enrichment days. Active behaviors were 39.79% higher (P<0.0001) on Post enrichment days compared to Baseline days. Total active behaviors were 44.24, 49.42, and 64.27% higher (P<0.0001) in week 3 compared to weeks 1, 2, and 4, respectively, and increased 35.93 and 29.36% higher (P<0.0001) in weeks 1 and 2, respectively, compared to 4. Location changes were greater (P<0.05) in week 3 compared to 2 or 4. No other measures were statistically different. In conclusion, pork by-products contain a wide range of nutrients and minerals, and employing a head as environmental enrichment increased active behaviors of large exotic felids and did not lose novelty.

Keywords: cats, stereotypy, zoo, novel

Introduction

In North American zoos, the diet of carnivores commonly consists of ground, raw meat diets, typically horse or beef-based. While these diets have been formulated to meet nutrient requirements of cats (NRC, 2006), they do not fulfil other non-nutritive requirements, which include diet consumption activities (locating, capturing, and killing prey), psychological aspects related to the feeding process (i.e. palatability and physical characteristics of food), and oral health needs (Lindburg, 1988). An example of oral health concerns includes misaligned molars, leading to irritation of the oral mucosa and resulting focal palatine erosion (FPE), where decayed and impacted food may compromise the oral cavity (Fitch and Fagan, 1982; Zordan et al., 2012). Felids fed carcasses in captivity have been observed to exercise the use of their feet, teeth, jaws, and head to tear meat from bones while felids fed only processed diets displayed none of these behaviors (Bond and Lindburg,
Additionally, this lack of mastication associated with ground diets fed in captivity is thought to alter skull formation when comparing wild and captive felids (Hartstone-Rose, 2014) leading to discrepancies in the region of the skull where most muscle attachment (sagittal crest) (Duckler, 1998), accelerated skull growth (Smuts et al., 1978), and shorter skulls with reduced cranial volumes (Hollister, 1917) when comparing captive and wild felids.

In the wild, felid species spend a considerable proportion of their time searching, capturing, and consuming prey. Lindburg (1988) reported that Bengal tigers cover 16 to 32 km on an average nightly hunt (searching) with only a 5% success rate and a cheetah with cubs may commit 40% of her time searching for food (Lindburg, 1988). In captivity, much, if not all, of the searching aspect of hunting is eliminated because food is easily available with little to no competition. Felids may fill this extra time by increasing their lying postures or may demonstrate stereotypies, particularly prior to feeding time (Carlstead, 1998; Clubb and Vickery, 2006).

Zoo caregivers have implemented environmental enrichment (EE) devices that increase normal behaviors and in turn improve welfare. However, EE devices or modifications must be biologically relevant to the animal, maintain novelty, and not be detrimental to their health (Sambrook and Buchanan-Smith, 1997; Tripp, 1985). In addition, some zoo management and exhibit design require EE appear natural and blend with the design of the animal exhibit. For the cat, a biologically relevant device could be their food presented in a natural form such as whole prey or whole by-products (i.e. bones, legs, heads, etc.).
Today, approximately 40% of live pig weight harvested for human consumed pork products is discarded to rendering facilities (SSR, 2014) and the typical dressing percent range is 68 to 77% (SDSU, 2015). Since 1927, however, more than 70% of rendering facilities (Bisplinghoff, 2006; Meeker, 2009) have closed due to heightened emission and air pollutant regulation by the Environmental Protection Agency (EPA) (EPA, 1995; Morrow and Ferket, 2001). These closures have increased the cost of sending meat by-products to rendering. Swine producers have expressed interest in increasing pork value through value added by-products (Buhr, 2004; NPB, 1999) and continue to look for avenues other than rendering to improve the value of the harvested animal. Many by-products sent to rendering, including large bones (femur, humerus, heads), snouts, and tails are high in valuable nutrients and cartilage; therefore, have potential for use as biologically relevant enrichment devices for felids and other carnivores managed in zoos. The objectives of this experiment were to: 1) evaluate 11 pork-based by-products for chemical and mineral composition and 2) determine if a pig head would be a biologically relevant EE device for large felids managed in a zoological setting.

Materials and Methods

Animal care and husbandry protocols were approved by Omaha’s Henry Doorly Zoo and Aquarium’s (Omaha) (Omaha, NE) Animal Care and Use Committee (IACUC) for the felids housed there and the Iowa State University’s IACUC Committee for the single animal housed at the Blank Park Zoo (Blank Park), Des Moines, IA.

Enrichment Item Analyses

Eleven pork by products for consideration as enrichment items for carnivores, including: heads, snouts, femurs, humerus, scapulas, ribs, necks, feet, tails, lower jaws, and
ear canals, were analyzed for nutritional composition (Table 5.1). All items were passed twice through a mechanical grinder (Buffalo No. 66BX Enterprise, St. Louis, MO), and then passed twice through a Hobart 52 grinder with a 5-mm die (model number 4046; Hobart Corporation, Troy, OH) for homogenization. Samples were then frozen and freeze dried for 4 days (vacuum/freezer: Uni-Trap by Cenco Model #10-100; vacuum chamber: Virtis Model #10-104-LD). Grinding and freeze drying were conducted at Iowa State University. After freeze drying, samples were ground through a 2-mm screen (Wiley mill, model 3383-L10, Thomas Scientific, Swedesboro, NJ) and analyzed for chemical composition. Enrichment items were analyzed for dry matter (DM) (Method 934.01) and organic matter [OM (Method 942.05) AOAC, 2006]. Crude protein (CP) was determined using a Leco Nitrogen/Protein Determinator (Method 992.15) (model FP-528, Leco Corporation, St. Joseph, MI). Fat concentrations were determined by hexane extraction ((Method 991.36) AOAC, 1995). Protein to fat ratios were calculated by dividing protein concentration by fat concentration in each item. Gross energy (GE) was determined by bomb calorimetry (model AC 500, Leco Corporation, St. Joseph, MI). Crude fiber (CF) was determined by Midwest Laboratories [(Omaha, NE) (AOCS Ba6a-05 (Thiex, 2008))]. Total dietary fiber (TDF) was also determined (Prosky et al., 1994) using triple the amount of protease and double the time for the water bath after addition of the protease, for a high protein sample. Mineral analysis was determined by Midwest Laboratories [(Omaha, NE) (Method 985.01) AOAC, 2000); (MWL ME PROC 29)] (Table 5.2). Chemical analyses were conducted at Omaha unless otherwise noted.
Study Animals and Location

A total of five captive large felids were used; four felids were located at Omaha and one at Blank Park (Table 5.3). Felids were housed individually and fed their normal amount and type of raw meat diet, without fasting days, and all were cared for by regular zoo staff. Space of animal enclosures ranged from 49.2 to 464.5 meters$^2$ and water sources were either electronic water bowls (Nelson Manufacturing Company, Model 760-10W, Cedar Rapids, IA, 52404, United States) or natural pools in the enclosure. Three felids were housed in cement/brick enclosures and two were housed in natural enclosures with dirt/grass ground and logs, rocks, trees, and stream/pools. Some felids had access only to indoors or outdoors, and two had access to both. Felids housed at Omaha were fed in the morning (between 07:30 to 09:00) with the raw meat diet offered in the public viewable portion of their enclosure and the felid at Blank Park was fed in the evening (between 17:00 and 18:00) and the raw meat diet was offered in the back holding quarters (Table 5.4). The experiment was conducted from June 30 to July 23, 2014.

Treatments and Experimental Design

The pen containing one large exotic felid was the experimental unit. The experimental design was a complete randomized design. Three treatment days were compared; Baseline (24 hours prior to the environmental enrichment device being placed into the pen), Enrichment (24 hours after the environmental enrichment device was placed in the pen) and Post enrichment (24 hours after the environmental enrichment device was removed from the pen).
**Environmental Enrichment Device**

All felids on this study had not previously been exposed to a pig head based on animal records and animal staff background information. Heads were provided by Sustainable Swine Resources, LLC, and were shipped, frozen, to Omaha and stored frozen at -18°C until 24 hours prior to offering, at which time they were moved to a cooler (2°C). Each head still contained the brain, eyes, teeth, bone, as well as some muscle and fat. The lower jaw was removed. On Baseline and Post enrichment days, the head was not offered. Instead the zoos provided their routine environmental enrichment devices per standard operating procedure. These environmental enrichment devices included a maximum of two daily and could include: plastic balls, plastic cylinders, plastic logs, plastic crates, and newspaper. Throughout the four week study, each felid had nearly equal access to these items. No scents or food items were used as enrichment during this study.

**Placement of the Environmental Enrichment Device**

Each felid enclosure was divided into 6 equal location sections. This was done by dividing each enclosure into latitudinal halves and then each half into three equal sections longitudinally. For ease of tracking during observation, landmarks (logs, bricks, trees, rocks, etc.) already present in the enclosure were used to distinguish one section from the next. All felids were released from section 1 (defined as the first section that each felid had access to upon release from back holding quarters). Section 2 was the middle section on the same latitudinal half as section 1. Section 3, on the same latitudinal half as sections 1 and 2, was the farthest from the felids release. Section 4 was directly adjacent to section 3, on the opposite latitudinal half. Sections 5 and 6 were directly adjacent to sections 2 and 1, respectively (Figure 5.1). Enrichment items were placed in sections farthest from the cat’s
release, so that diet and enrichment were equidistance from the felid when it entered the
enclosure. The exception to this was the Bengal tiger housed at Omaha that received
enrichment and diet in sections closest to its release, still equidistance from the cat. This was
due to this cat receiving food in a cove area of the enclosure that protected from birds
consuming the food, which could not be moved.

Measures

Head Weight Loss

Each head was individually weighed to the nearest 0.1g (Mettler Toledo XP8001M
Precision Balance, Columbus, OH, 43240, United States) 24 hours prior to placement in the
enclosure. The head was placed in the cat’s enclosure on the morning of Enrichment days
and approximately 24 hours later, the head was removed and re-weighed using the same
scale as before. The difference between the initial and ending head weight was recorded as
head weight loss (g). Intrinsic head weight loss (g) was measured to determine weight loss
from thawing and dehydrating. This was done by weighing three heads (3, 3.5, and 4 kg in
weight) while frozen, and re-weighing after 24 hours when housed, untouched, at 24° C.
Difference between each starting and finishing weight was defined as intrinsic head weight
loss.

Nutrient intakes, from head consumption only, were calculated based on
macronutrient composition of heads (values from Table 5.1), head weight loss, and intrinsic
losses. This was done by multiplying head weight loss (grams) by intrinsic loss (%) and
subtracting that value from head weight loss, to give actual intake (g) [actual intake = (head
weight loss) - (head weight loss * % intrinsic loss)]. Macronutrient concentration (%) was
then multiplied by actual intake (grams) to yield intake (grams) of each macronutrient from consuming the head (Table 5.5).

**Meat to Bone and Fat to Bone Ratios**

Meat to bone and fat to bone ratios were determined by manually separating meat and fat from skull bone using hand-held knives. Meat, fat, and skull (including brain) components were then weighed separately to the nearest 0.1g (Mettler Toledo XP8001M Precision Balance, Columbus, OH, 43240, United States) and ratios were calculated (Table 5.5).

**Orts and Fecal Scores**

Each felid received the same amount of their respective raw meat diet during the study as it had previously been receiving. Leftover diet (orts) and fecal scores were collected by zoo keepers or an observer each morning. Diet orts were weighed and fecal scores were visually assessed on a five point scale of: 1=hard, dry pellets; 2=dry, well-formed; 3=soft, moist, formed; 4=soft, unformed; 5=watery liquid (Felid TAG, 2014). Orts will be presented descriptively and fecal scores will be presented statistically (Table 5.5).

**Behavior**

An ethogram for the current study was adapted from previously published felid ethograms (Skibiel et al., 2007; Wells and Egli, 2004) prior to the start of the study. Felid behaviors and postures were allocated to three categories: active, inactive, and other (Table 5.6). The grouping of active behaviors included: locomotion, standing, rolling, exploring, grooming, head over water, vocalizing, interest in item, interaction with item, interest in diet, interaction with diet, and spraying behaviors/postures. Inactive grouped behaviors included: laying and sitting; and other grouped behaviors included: eliminatory and other behaviors/postures.
Felids were released from their holding quarters each morning between 07:30 and 09:00. One minute instantaneous scan samples (Altmann, 1974) of behaviors began when the cat’s nose broke the door barrier upon release from back holding quarters, and continued for 120 minutes. The first scan was made one minute from the felid crossing the door barrier. Location sections the felid was in were observed using sampling at 5-minute intervals. A cat’s nose had to be inside the location for it to be noted in that location section.

A total of 6 observers were used. One trainer with previous experience observing large exotic felids was responsible for observer training prior to study commencement. Inter-observer similarity testing took place over three sessions using videos of large felids recorded at Omaha. All observers independently reviewed the same video for 10 minutes using the ethogram (Table 5.6) used for this study. Each observer scored what the large felid was doing using a one min scan sampling technique (Altmann, 1974). Inter-observer agreement was adequate at ≥ 93% (Caro et al., 1979; Martin and Bateson, 1993).

Temperature and Relative Humidity

Temperature and relative humidity were recorded every 10 min for the duration of the study using HOBO sensors (HOBO Model H08-003-02, Onset Computer Corp., Bourne, MA, 02532, United States). One sensor was placed outdoors under an awning, affixed to a light fixture using zip ties, approximately 5 meters from the ground. The other sensor was placed in the indoor area of one of the cat’s enclosure, on a window cutout, approximately 4 meters from the ground. Data were transferred to a computer using HoboWareLite. Data were averaged for the two hours that felids were observed, using averages from the sensor in which the felid had access (i.e. felids that only had indoor access only used the average of the
sensor placed indoors; felids with both indoor and outdoor access used an average of both indoor and outdoor sensor data).

**Statistical Analysis**

All data were evaluated for normal distribution before analysis by using the UNIVARIATE procedure of SAS (SAS Institute Inc., Cary, NC). Data used to evaluate active, inactive and other behaviors and postures, location change, time to approach head and orts failed to meet the assumption of normally distributed data. These data were analyzed using the GLIMMIX procedure of SAS. The active, inactive, and other behaviors and postures model included the fixed effect of treatment (week, day and week*day interaction) and the random effect of cat. Average relative humidity was used as a quadratic covariate for active and inactive behaviors. A binomial distribution was noted and used in the evaluation by using the GLIMMIX procedures. The location change model included the fixed effect of treatment (week and day) but a Poisson distribution was noted and used in the evaluation by using the GLIMMIX procedures. The day*week interaction as well as temperature, relative humidity, and enclosure dimension were not significant and therefore were removed from the final model. The head weight loss model included the fixed effect of treatment (week) and the random effect of cat. The time to approach the head model included the fixed effect of week and the random effect of cat. A Gamma distribution was noted and used in the evaluation. A default significant convergence had to be relaxed from $1 \times 10^{-8}$ to 0.0001. Further, the I-Link option of SAS was used to transform the mean and SE values back to the original units of measure. Data used to evaluate fecal scores did meet the assumption of normally distributed data. These data were analyzed using the MIXED procedure of SAS. The model included the fixed effect of treatment (day week) and the random effect of cat.
The day*week interaction as well as temperature, relative humidity, and enclosure dimension were not significant and therefore were removed from the final model. PDIIFF was used and a P value of \( \leq 0.05 \) was considered significant. Mutually exclusive felid postures and behaviors, chemical and mineral composition of various pork-based enrichment items, orts, and minimum and maximum time to approach the head are presented descriptively.

Results

Enrichment Item Analyses

The head was composed of 48.51% DM, 60.70% OM, 38.41% CP, 22.01% fat, 13.48% CF, 3.44% TDF, and 4.09 kcal/gram GE. It contained the second highest concentration of zinc (117.7 ppm) and magnesium (0.27%) and contained the highest concentration of phosphorus (6.64%) and calcium (13.69%) content of any other pork item analyzed (Ca:P=2.06). All values are on a dry matter basis.

Ranges of nutrient compositions for all 11 enrichment items are as follows: DM: 26.01-71.23%; OM: 53.04-96.79%; CP: 22.90-79.29%; fat: 22.01-63.15%; CF: 0.25-19.54%; TDF: 0.04-3.44%; GE: 3.73-7.45 kcal/gram. Protein to fat ratios ranged from 0.47 (tails) to 3.58 (snouts). Snouts were highest in OM, CP, sulfur, sodium, and copper while they were lowest in DM, CF, TDF, calcium, and phosphorus. Heads contained approximately 99% more TDF, calcium, and phosphorus compared to snouts. Humerus bones were highest in DM (71.23%) and lowest in iron (32.4%). Femur bones were lowest in sulfur (0.09%) and potassium (0.07%). Humerus and femur bones were both very low in copper (both 1.3 PPM) compared to snouts, which contained more than 4 fold more copper (5.6 PPM). Tails were highest in fat percentage and GE, containing nearly 3 times more fat and 2 times more kcals (GE) than heads and scapulas, while they were lowest in sodium (0.31%). Lower jaws were
highest in CF (19.54%) and contained more than 98% more CF than snouts, which contained the least CF (0.25%). Lower jaws also contained nearly 10 fold more magnesium and iron, and more than 4 fold more manganese than items which had lowest concentrations of those minerals. Ear canals contained less than half the amount of zinc as did ribs, but were highest in potassium, along with necks (both 0.31%) (Tables 5.1 and 5.2).

**Head Weight Loss**

Weight loss of the head (grams) was not different across the 4 weeks (543.43 ± 220.89, 587.60 ± 220.89, 555.09 ± 223.87, and 700.32 ± 223.87, respectively; P=0.37). Starting weight of the frozen heads used to determine intrinsic weight loss were; 3117.5, 3524.8, and 3949.1 grams. Ending weights after sitting, untouched, for 24 hours at 24° C were 3051.3, 3443.0, and 3857.9 grams, respectively. Therefore, intrinsic weight loss was 2.12, 2.32, and 2.31%, respectively, of starting frozen weight.

Average nutrient intakes were 298.78, 373.86, 236.57, and 135.56 grams for DM, OM, CP and fat, respectively. Gross energy average intake was 2519.09 kcals. Minimum and maximum nutrient intakes were variable and ranged between 73.17 and 700.67 grams for DM, 91.56 and 876.74 grams for OM, 57.94 and 554.79 grams for CP, and 33.20 and 317.91 grams for fat. Likewise, gross energy intake was variable and ranged from 616.93 and 5907.56 kcals (Table 5.5).

**Meat to Bone and Fat to Bone Ratios**

There were 338.5 grams of fat and 658.0 grams of meat (including eyes) removed from the skull. Determination of fat and meat was made by the person separating the components, with white substance separated as fat and red being meat. The ending weight of the skull (with brain still included) was 2343.9 grams. The meat to bone ratio of the head was
0.28:1 and the fat to bone ratio was 0.14:1, with the brain still remaining in the skull (Table 5.5).

**Orts and Fecal Scores**

Numerically, orts did not differ by treatment day or week and fecal scores did not differ over treatment days (P = 0.77) or over the four weeks (P = 0.68; Table 5.5).

**Behavior**

Active behaviors were 55.70% higher (P<0.0001) on Enrichment days compared to Baseline and 26.42% higher compared to Post enrichment days. Active behaviors were 39.79% higher (P<0.0001) on Post enrichment days compared to Baseline days (Figure 5.2).

Active behaviors were highest (P<0.0001) in week 3 and, compared to weeks 1, 2, and 4, were approximately 44, 49, and 64% higher, respectively. Total active behaviors also were approximately 36 and 29% higher in weeks 1 and 2, respectively, compared to 4 (Figure 5.3).

Individual behaviors could not be analyzed statistically, likely due to small sample size and few/variable number of observations of those behaviors. Descriptively, of all individual behaviors and postures, locomotion and laying were the most frequently observed postures across all treatment days and weeks comprising approximately 80% of the total average time. The laying behavior was approximately 22% higher on Baseline compared to Enrichment days and sitting was approximately 64% higher on Baseline days compared to both Enrichment and Post enrichment days.

Interaction with the enrichment device increased approximately 98% on Enrichment compared to Baseline and Post enrichment days. Interestingly, interaction with an enrichment device was approximately 72% higher on Post enrichment compared to Baseline days, both being days on which standard zoo enrichment was offered. Interaction with the head did not
wane over the four week study with more observations of interaction with the enrichment occurring in weeks 3 and 4 (7.78 and 6.61%, respectively) than in weeks 1 and 2 (5.73 and 4.57%, respectively) (Table 5.7).

Average time to approach the head did not differ over the four weeks (P=0.45; Week 1 74.67 ± 50.27; Week 2 82.04 ± 55.23; Week 3 37.97 ± 27.04 and Week 4 36.88 ± 26.27 seconds). Descriptively, minimum time to approach the head was approximately 9 seconds, with a maximum time being approximately 292 seconds. There were no differences in the number of location section changes between Baseline (6.78 ± 1.46), Enrichment (7.52 ± 1.60), or Post enrichment (7.02 ± 1.51) days (P=0.67). Number of location section changes was greater (P<0.05) in week 3 (8.78 ± 1.92) compared to the other weeks (Week 1 7.22 ± 1.57; Week 2 6.73 ± 1.47 and Week 4 5.95 ± 1.35).

Discussion

Offering animal by-products as enrichment items has not been common in the past because of high costs, negative public perception, and health risks such as choking and splintering bones. These health issues do not commonly occur, however, and with proper handling and care (offering raw bones instead of cooked and offering appropriately sized bones), their risk is minimized. Negative public perception also may be mitigated if the food increases the animal’s activity, therefore increasing visitor enjoyment.

The objectives of this study were to evaluate 11 pork by-products for chemical and mineral composition and determine if a head would be a biologically relevant environmental enrichment device for large felids managed in a zoological setting. This was evaluated by determining if the pig head offered would stimulate active behaviors in large felids, compared to other nonfood enrichment items and ascertaining if there were differences in
consummatory and appetitive behaviors before, during, and after the head was offered. Offering environmental enrichment to animals managed in captivity can help combat stereotypies that may arise. Additionally, employing the use of biologically relevant enrichment has the potential to improve animal welfare through possible impact on dental and physiological health. A variety of species and animals with a wide age range were used in this study, but separating age and species affects was not an intention of this study. By evaluating behavioral response of different species with various ages, results of this study have more broadly reaching effects and implications.

**Enrichment Item Analysis**

In addition to the heads, ten additional pork by-product items were analyzed for chemical and mineral composition. These by-products have the potential for use as enrichment items, similar to the heads; however, an understanding of the potential nutritional impact of using these items as environmental enrichment needed evaluation. The enrichment items analyzed had an extremely wide range of compositions. This range offers a selection based on nutrient(s) of interest or need. Furthermore, the Ca:P ratio of a majority of the enrichment items was around 2:1, which is close to what has been suggested to be ideal for felids (Kienzle et al., 1998), meaning mineral intake will not be severely disrupted if enrichment items are consumed. Snouts contained the highest concentration of OM (96.79%) and CP (79.29%), and lowest DM (26.01%), CF (0.25%), and TDF (0.04%) composition. Snouts also were the second lowest in fat (22.16%), but were the third highest in GE (6.21 kcal/g).

If an animal needs more calories without increasing fat, snouts would be an option because the protein to fat ratio was high (3.58). Conversely, if increasing caloric intake is
desirable without increasing protein (for an animal with kidney problems, for example) tails would be an option because of their low protein to fat ratio (0.47). Similarly, many of the bone enrichment items (heads, jaws, humers, etc.) are high in calcium and phosphorus, making them a good way to increase calcium consumption, and because the Ca:P ratio is near ideal, mineral imbalance will likely not be an issue. It is important to note that if animals routinely receive enrichment items, other food and diet should be adjusted or formulated accordingly to account for nutrients coming from these items and prevent obesity, nutrient imbalance, or over nutrition.

The high protein concentration in snouts, and many of the evaluated enrichment items, likely comes from high collagen content in those items. Collagen is the most abundant protein in animals (Shoulders and Raines, 2009), and makes up more than 70% of cartilage dry weight (Rogov et al., 1992). Furthermore, Rogov et al. (1992) showed that including collagen as 15 to 20% of total proteins in a beef-based diet increases the biological value of protein by more than 8% compared to no inclusion of collagen and also leads to the highest protein utilization. Therefore, offering enrichment items high in collagen as part of routine diet may be beneficial. Analyzing collagen strictly as protein, however, may be misleading. Because connective tissue proteins such as collagen are thought to be poorly digested, this form of protein may be more appropriately analyzed as animal fiber.

Fiber, both crude and total dietary, was low for most items analyzed in this study (as low as 0.25% CF and 0.04% TDF). These fiber assays, developed to capture plant-based fibers do not currently account for animal-based components accurately; therefore, the value of actual animal fiber in these items is likely underestimated with the current assays. Recently, the concept of animal fiber (hair, bones, cartilage, etc.) has received more attention
and inclusion in raw diets, in the form of whole prey, for felids has been shown to reduce phenol and indole production by 65.54 and 61.38%, respectively, in cheetahs fed whole prey versus ground raw meat diets, possibly improving gut health (Depauw et al., 2013). Additionally, fiber can function as a pre-biotic, appetite regulator, and produce valuable short-chain fatty acids that provide energy for the large intestine (Fahey et al., 2003). An assay analyzing for animal fiber specifically would more accurately reflect the fiber present in the enrichment items used in the current study. Evaluation of animal-based fiber in carnivore diets and enrichment items should be researched further.

**Environmental Enrichment Device**

The enrichment item used in this study was a head (with lower jaw removed and eyes, brain, teeth, and some fat and meat still intact). The heads had starting weights ranging from 2776.0 to 4495.1 grams (6.12 to 9.91 lbs). The meat to bone (0.28) and fat to bone (0.14) ratios indicate the majority of the head was skull bone; however, a substantial portion of the head could be manipulated and consumed. It is likely that much of the caloric contribution the animal would receive from the head would come from these portions. In the current study, none of the felids fully consumed the head, nor did they reach the brain cavity of the skull. No health issues arose from the offering of a head during this study. Further investigation into amount of calories felids actually consume from the head is warranted.

**Head Weight Loss and Nutrient Intake**

Loss of head weight was not significantly different across weeks, but was numerically highest in week 4. This indicates, again, that novelty of the head did not wane over the course of four weeks. Zoos look for enrichment that animals will interact with and items that will keep animal attention, to avoid constantly searching for new enrichment. The head kept felid
interest and did not lose its novelty over four weeks, which may indicate it can be used as enrichment on a long term basis. This should be further studied by extending the study period beyond four weeks.

Intrinsic weight loss was determined in order to differentiate inherent loss from the loss due to consumption by the cat. From a practical implication standpoint, this can be used to determine if the felid actually interacted with or ingested any part of the head. For example, if a 3.6 kg head only lost 100 grams after being offered to an animal, it is likely due strictly to intrinsic losses and the felid may have interacted minimally with the item; therefore, received little to no nutrients or calories. This can then be used to make adjustments to the animal’s typical diet to ensure the proper amount of calories and nutrients are consumed. Further research should be conducted on intrinsic losses at varying temperatures.

Calculations of nutrient intakes can be used to adjust regular diet amounts based on degree of enrichment item consumption by an animal. Nutrient intake from consuming the heads was highly variable. Averages are presented to give a general idea of consumption and intake, but it is also important to look at minimum and maximums. In the current study, there was nearly a 500 gram difference in minimum and maximum protein intake and more than a 5,000 kcal difference in GE intake. For this reason, it is important to evaluate the loss of weight (i.e. consumption) in enrichment items for each animal individually. One animal may be getting 6,000 kcals from consuming an enrichment item, but another animal may only get 600. This concept can be used to evaluate intake of certain minerals as well. This may be useful for monitoring calcium and phosphorus intake, for example. Adjustments in regular diet should reflect this to avoid under nutrition and nutrient deficiencies.
Macronutrient and energy digestibility was not evaluated in this study. Without knowing digestive efficiency, GE is the best estimate of caloric intake. If metabolizable energy (ME) is of interest, Atwater and modified Atwater factors could be used to calculate and predict ME. Atwater values (9 kcal/g fat, 4 kcal/g protein, 4 kcal/g carbohydrate) or modified Atwater values (8.5 kcal/g fat, 3.5 kcal/g protein, 3.5 kcal/g carbohydrate) multiplied by fat, protein, and carbohydrate content can be used to calculate ME (NRC, 2006). Carbohydrate content can be calculated by finding nitrogen free extract (NFE) in the following equation: (100-(%ash+%CP+%fat+%TDF)). Due to assay error (likely TDF) NFE of some items may be a negative number, in which case a value of zero should be used for NFE. Using these calculations, ME for heads is calculated to be 3.52 kcal/g using Atwater factors and 3.22 kcal/g using modified Atwater factors. Digestible energy should also be evaluated in the future to assess if the use of these Atwater factors is appropriate.

**Orts and Fecal Scores**

Orts of standard raw meat diets were monitored to determine the effect of offering a head on diet consumption. Amount of orts could not be statistically analyzed, but numerical day and week means are indicative of diet intake not being negatively affected by the head. Fewer orts on Enrichment and Post enrichment days compared to Baseline indicate that felids ate more on those days. More orts on week 4 and fewest orts in week 3 may be explained by the fluctuation in temperatures during those weeks (highest average temperature on week 4 and lowest on week 3). Average fecal scores (a score of 3.0 being considered ideal) were similar between all days and weeks, ranging from 3.56 to 3.79. There were no differences observed in fecal scores between any days or weeks. There is no evidence that the offering of
a pig head negatively affected diet consumption or fecal scores. This indicates that overall health of the animals was not negatively affected by partial consumption of the head.

**Behaviors**

Enrichment that takes into account the natural history and inherent interest and natures of an animal is said to be biologically relevant (Mellen and Sevenich MacPhee, 2001; Rollin, 1985). Offering biologically relevant enrichment may stimulate species specific behavior (Hunter et al., 2002; Smith et al., 1993) and reduce stress (Reed et al., 1993; Chamove, 1989). Biologically relevant enrichment for felids may involve hunting or consuming relevant food (i.e. animal parts) because a large portion of their time in the wild is spent hunting (Lindburg, 1988). In the current study, a pig head was used as a biologically relevant enrichment device.

Highest total active and fewest total inactive behaviors on Enrichment days (P<0.0001) suggests that the offering of the head as enrichment did increase activity compared to typical enrichment items (Baseline and Post enrichment days). Furthermore, higher (P<0.0001) activity on Post enrichment compared to Baseline days suggests there are sustained effects of increased activity that last past the point of removal of the head (Figure 5.2). This is relevant in a zoo setting because enrichment that has effects after removal is valuable both financially and from a management standpoint. The head may provide enrichment for the felid both on the day of offering and the day after removal, with minimal management changes.

Though there are few, previous studies analyzing the effect of provisioning of edible enrichment have been conducted, and show similar results as the current study. Offering one horse knuckle or beef shank to tigers (*Panthera tigris* (n=3)), ocelots (*Leopardus pardalis*)
(n=2)), cougars (Puma concolor (n=3)), cheetahs (Acinonyx jubatus (n=2)), and lions (Panthera leo (n=3)) resulted in nearly a 50% increase in active behaviors compared to no enrichment (Skibiel et al., 2007). Offering bones to African lions (Panthera leo (n=2)) and Sumatran tigers (Panthera tigris sumatrae (n=2)) twice per week resulted in increased (nonstereotypic) activity of lions by more than 66% compared to no enrichment (Bashaw et al., 2003). Bashaw and colleagues (2003) also observed a sustained increase in activity two days after the presentation of bones with activity being 40% higher than with no enrichment. Skibiel and colleagues (2007) found that increased activity in large exotic felids from provisioning of bones, frozen fish, and spices were not sustained after 7 days. The current study shows sustained effects one day post-enrichment, but longer lasting effects should be studied by observing behavior for multiple days post-enrichment.

Statistical analysis could not be performed on all individual behaviors; therefore, descriptive observation averages of behavior/posture performances (as percentage of total observations) are presented in Table 5.7. Differences in grouped behaviors (active, inactive, other) may be further highlighted with individual behavior data. Highest total active behaviors (P<0.0001) seen on Enrichment days is likely due to a 99.00% increase in interaction with the enrichment item compared to Baseline and Post enrichment days. Post enrichment activity being higher (P<0.0001) than Baseline is likely due to more observations of locomotion (17.40% increase), interaction with the enrichment item (72.22% increase), and interest in diet (60.00% increase) behaviors on Post enrichment compared to Baseline days. It is interesting to note that interaction with typical zoo enrichment was increased after the offering of the head (between Baseline and Post enrichment). The offering of a head once a week has the potential to increase interest in typical enrichment (balls, logs, newspaper,
etc.) offered on other days, and this should be further investigated. Noting occurrence of interaction with enrichment did not decrease across the four weeks of the current study suggests novelty of the head did not wear off, with felid interest still being held after four consecutive weeks of access to the head.

Fewer total active behaviors and more inactive behaviors in week 4 were likely due to temperature, as average temperature was as much as 4.83°C higher in week 4 (27.09°C) compared to other weeks (23.02, 25.12, and 22.26°C in weeks 1, 2, and 3, respectively). Similarly, lowest average temperatures were observed in week 3 and correspond to highest total active and lowest inactive behaviors (Figure 5.3). Although temperature and relative humidity were accounted for as covariates in statistical analysis, weather may have impacted factors beyond the author’s control that could not be accounted for. This could be looked into farther in future research by assessing precise influence of temperature on behavior and activity, possibly by repeating the study over various seasons.

Across weeks, there was no significant difference in average time to approach the head. The range of time to approach (minimum and maximum) being as low as 3 seconds (in week 3) and as high as 360 seconds (in week 4) shows that not all felids reacted to the enrichment in the same way. What is successful with one felid will not be successful with all others, and this should be considered when offering any enrichment. For example, tigers (Panthera tigris) showed a 22% increase in active behaviors while lions (Panthera leo) showed a slight decrease in active behaviors with the use of spices (chili powder, cinnamon, and cumin) as enrichment (Skibiel et al., 2007). However, on average, time to approach the enrichment item was numerically reduced (75 to 37 seconds) over the four week study, indicating the novelty effect of the head did not wear off.
It is important to access the novelty effect of an enrichment item to ascertain if increases in activity or interest in objects are sustained over time. Other studies have found that animals may become habituated to enrichment and lose interest with repeated exposure, such as minipigs (*Sus scrofa domestica*) losing interest in cones (Smith et al., 2009) and cynomolgus monkeys (*Macaca fascicularis*) becoming habituated to enriched (swings, ropes, balls) housing (Bryant et al., 1988). This has also been observed in cats. Captive black-footed cats (*Felis nigripes*) became habituated to olfactory enrichment (different odors/scents) and exploration of scented cloths declined by nearly 80% between day 1 and day 5 of exposure (Wells and Egli, 2004). However, habituation is not always the case as giant pandas (*Ailuropoda melanoleuca*) remained responsive to enrichment (plastic objects, burlap sacks, branches, frozen fruit, and puzzle feeders) over 15 enrichment sessions (Swaisgood et al., 2001). Large captive exotic felids do not appear to become habituated to pig heads over four weeks of exposure, and future studies could assess longer study lengths.

Number of location section changes were not different between days but were numerically highest on Enrichment days, which may indicate heightened activity with the offering of the head. Location section changes were more abundant in week 3 compared to 2 or 4 which could, again, be due to lowest average temperatures occurring that week.

Stereotypies have been defined as repetitive, invariant patterns in an animal’s behavior that serve no obvious function or goal and may arise out of stress, frustration, or lack of stimulation (Mason, 1991). Managed carnivores are particularly prone to stereotypies (Clubb and Mason, 2003), possibly because hunting, searching, and consumption activities, that require much of their time in the wild, are reduced or removed in captivity and may be replaced with an unnatural behavior. A review of 25 published zoo-conducted studies
assessing effect of enrichment (objects, olfactory, training, exhibit changes, feeding) on stereotypies found that offering enrichment reduced stereotypic behavior expression in 53% of cases (herbivores, carnivores, and omnivores included) (Swaisgood and Shepherdson, 2005).

Zoo visitors also are aware of stereotypic behaviors and their negative impact on animal health. In one study, zoo visitors identifying stereotypic behavior indicated the animal wasn’t behaving naturally and also rated the behavioral welfare of the animal lower than when stereotypic behaviors were absent (Godinez et al., 2013). Zoos now strive to not only entertain their guests, but also educate them. This can be difficult when the average zoo visitor spends as few as 12 seconds at an individual animal exhibit (Altman, 1998). If the attention of visitors can be captured and kept by an animal, they will remain at that exhibit longer and it has been found that activity of an animal greatly influences guest duration at exhibits by as much as 100% (Bitgood et al., 1986). Additionally, animal activity directs guest conversation and attention toward the animal (Altman, 1998), increasing time, attention, and educational opportunities. In the current study, offering a pig head as enrichment increases animal activity and thus has the potential to retain guests at exhibits longer and this should be evaluated in future research. Along with visitor education, public pressure (Young, 2003) and requirement for Association of Zoos and Aquariums (AZA) accreditation (AZA, 2014) has led zoos to offer enrichment more in recent years.

Results of this study are valuable for animal managers in zoological institutions that aim to increase animal activity through environmental enrichment while understanding the nutritional implications as well. Felid manipulation of pig heads required chewing, gnawing, and use of paws for tearing and consumption. This can help fulfill nonnutritive requirements
of felids that are not always met by a commercially processed soft, raw diet and further studies should investigate the impact of these types of enrichment items on oral health as well as explore interaction with the pig head in more detail (i.e. quantify use of paws, jaws, and teeth). In the current study, offering captive large exotic felids enrichment in the form of a pig head more than doubled active behaviors compared to the day before offering this enrichment. Higher occurrence of active behaviors was sustained the day after offering this enrichment. Animals of varying ages and sizes were involved in the current study, making results broadly applicable to many individuals in zoos. Similar research is warranted in other large felid species and small exotic felids to determine if results are similar across species and with the use of various pork by-products as the enrichment item. Further research with these enrichment items may also be conducted to directly address their effects on stereotypies in animals known to display them and effect of varying predictability (placement and timing of offering) of the head.

**Value for Pork Producers**

As mentioned previously, costs associated with rendering have increased because of fewer rendering plants and farther transport distances. In 2002, remaining rendering plants charge as much as $60 per pig for carcass pickup (Bonhotal et al., 2002). That means that in a 1,500 head operation, assuming 5% annual death loss, for example, producers pay $4,500 per year for carcass pickup. Currently pig heads being sold to industries other than rendering, the zoo industry for example, are generating six times more value than rendering would (SSR, 2014). This leads to producers making six times more money selling these by-products to markets other than rendering while saving $4,500 on carcass pickup associated with rendering. This can also be applied to other by-products sold as enrichment items.
Conclusions

In conclusion, a pig head can be used as biologically relevant environmental enrichment for captive large exotic felids and increases activity of these animals compared to typical, inedible enrichment items. This heightened activity is sustained the day after removing the head and the head does not lose its novelty after four consecutive weeks of being offered. When offered, pig heads do not negatively affect diet composition or fecal scores, and no negative clinical signs were seen in animals offered the enrichment. A variety of pig by-products have been shown to be nutritionally rich and diverse, and may have the potential to be used as environmental enrichment for captive exotic carnivores. Ingestion of these enrichment items, however, is variable between animals so individual intakes should be accounted for when managing nutrition. Additionally, the use of pork by-products as enrichment for captive animals is truly advantageous to pork producers and zoological institutions alike.

Literature Cited


AOAC, 1995, Official Method 991.36, Fat (crude) in meat, solvent extraction (Submersion) method: Official Methods of Analysis.


NPB, 1999, Case studies of value added pork production & marketing, National Pork Board.


SDSU, 2015, Swine Grading, Brookings, SD, South Dakota State University.


SSR, 2014, Unpublished, Sustainable Swine Resources.

Swaisgood, R. R., and D. J. Shepherdson, 2005, Scientific approaches to enrichment and stereotypies in zoo animals: what's been done and where should we go next?: Zoo Biology, v. 24, p. 499-518.


### Table 5.1. Chemical Composition of Various Pork-Based Enrichment Items (DM basis)

<table>
<thead>
<tr>
<th>Item</th>
<th>%DM</th>
<th>%OM</th>
<th>%CP</th>
<th>%Fat</th>
<th>Protein:Fat Ratio$^2$</th>
<th>%CF</th>
<th>%TDF</th>
<th>GE (Kcal/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heads</td>
<td>48.51</td>
<td>60.70</td>
<td>38.41</td>
<td>22.01</td>
<td>1.75</td>
<td>13.48</td>
<td>3.44</td>
<td>4.09</td>
</tr>
<tr>
<td>Snout</td>
<td>26.01</td>
<td>96.79</td>
<td>79.29</td>
<td>22.16</td>
<td>3.58</td>
<td>0.25</td>
<td>0.04</td>
<td>6.21</td>
</tr>
<tr>
<td>Femur</td>
<td>70.76</td>
<td>65.41</td>
<td>22.90</td>
<td>34.63</td>
<td>0.66</td>
<td>12.25</td>
<td>2.21</td>
<td>5.10</td>
</tr>
<tr>
<td>Humerus</td>
<td>71.23</td>
<td>61.59</td>
<td>23.22</td>
<td>31.44</td>
<td>0.74</td>
<td>11.44</td>
<td>2.37</td>
<td>4.72</td>
</tr>
<tr>
<td>Scapula</td>
<td>61.98</td>
<td>53.53</td>
<td>32.67</td>
<td>22.61</td>
<td>1.44</td>
<td>10.73</td>
<td>2.84</td>
<td>3.73</td>
</tr>
<tr>
<td>Ribs</td>
<td>43.12</td>
<td>74.27</td>
<td>41.59</td>
<td>32.21</td>
<td>1.29</td>
<td>0.97</td>
<td>1.11</td>
<td>5.52</td>
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<tr>
<td>Neck</td>
<td>49.90</td>
<td>63.81</td>
<td>38.43</td>
<td>24.15</td>
<td>1.59</td>
<td>1.58</td>
<td>1.63</td>
<td>4.39</td>
</tr>
<tr>
<td>Feet</td>
<td>48.21</td>
<td>76.56</td>
<td>54.31</td>
<td>23.13</td>
<td>2.35</td>
<td>5.18</td>
<td>1.52</td>
<td>4.85</td>
</tr>
<tr>
<td>Tails</td>
<td>50.23</td>
<td>91.12</td>
<td>29.38</td>
<td>63.15</td>
<td>0.47</td>
<td>1.66</td>
<td>2.15</td>
<td>7.45</td>
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<td>Lower Jaw</td>
<td>60.67</td>
<td>53.04</td>
<td>29.11</td>
<td>22.89</td>
<td>1.27</td>
<td>19.54</td>
<td>1.72</td>
<td>4.15</td>
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<tr>
<td>Ear Canals</td>
<td>36.37</td>
<td>96.78</td>
<td>58.31</td>
<td>39.02</td>
<td>1.49</td>
<td>0.72</td>
<td>1.59</td>
<td>6.84</td>
</tr>
</tbody>
</table>

$^1$ Abbreviations used: DM, Dry matter; OM, organic matter; CP, crude protein; CF, crude fiber; TDF, total dietary fiber; GE, gross energy

$^2$ Protein:fat ratios were calculated by dividing protein concentration by fat concentration of each item
Table 5.2. Mineral Composition of Various Pork-Based Enrichment Items (DM basis)

<table>
<thead>
<tr>
<th>Item</th>
<th>Ca:P Ratio&lt;sup&gt;2&lt;/sup&gt;</th>
<th>Ca</th>
<th>P</th>
<th>S</th>
<th>K</th>
<th>Mg</th>
<th>Na</th>
<th>Fe</th>
<th>Mn&lt;sup&gt;3&lt;/sup&gt;</th>
<th>Cu</th>
<th>Zn</th>
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</thead>
<tbody>
<tr>
<td>Heads</td>
<td>2.06</td>
<td>13.69</td>
<td>6.64</td>
<td>0.26</td>
<td>0.30</td>
<td>0.27</td>
<td>0.60</td>
<td>171.1</td>
<td>2.1</td>
<td>3.9</td>
<td>117.7</td>
</tr>
<tr>
<td>Snout</td>
<td>3.75</td>
<td>0.15</td>
<td>0.04</td>
<td>0.57</td>
<td>0.60</td>
<td>0.04</td>
<td>0.72</td>
<td>170.2</td>
<td>2.6</td>
<td>5.6</td>
<td>49.7</td>
</tr>
<tr>
<td>Femur</td>
<td>2.07</td>
<td>10.58</td>
<td>5.12</td>
<td>0.09</td>
<td>0.07</td>
<td>0.21</td>
<td>0.45</td>
<td>66.5</td>
<td>n.d.</td>
<td>1.3</td>
<td>90.1</td>
</tr>
<tr>
<td>Humerus</td>
<td>2.07</td>
<td>11.54</td>
<td>5.58</td>
<td>0.10</td>
<td>0.09</td>
<td>0.23</td>
<td>0.49</td>
<td>32.4</td>
<td>n.d.</td>
<td>1.3</td>
<td>102.2</td>
</tr>
<tr>
<td>Scapula</td>
<td>2.13</td>
<td>13.40</td>
<td>6.29</td>
<td>0.17</td>
<td>0.15</td>
<td>0.25</td>
<td>0.62</td>
<td>45.8</td>
<td>n.d.</td>
<td>1.4</td>
<td>102.3</td>
</tr>
<tr>
<td>Ribs</td>
<td>1.98</td>
<td>8.69</td>
<td>4.40</td>
<td>0.32</td>
<td>0.58</td>
<td>0.17</td>
<td>0.44</td>
<td>103.3</td>
<td>n.d.</td>
<td>2.4</td>
<td>121.1</td>
</tr>
<tr>
<td>Neck</td>
<td>2.08</td>
<td>11.57</td>
<td>5.57</td>
<td>0.24</td>
<td>0.31</td>
<td>0.23</td>
<td>0.54</td>
<td>72.5</td>
<td>n.d.</td>
<td>1.6</td>
<td>115.7</td>
</tr>
<tr>
<td>Feet</td>
<td>2.07</td>
<td>8.33</td>
<td>4.02</td>
<td>0.34</td>
<td>0.18</td>
<td>0.13</td>
<td>0.55</td>
<td>97.0</td>
<td>n.d.</td>
<td>1.8</td>
<td>69.8</td>
</tr>
<tr>
<td>Tails</td>
<td>1.90</td>
<td>2.99</td>
<td>1.57</td>
<td>0.19</td>
<td>0.26</td>
<td>0.06</td>
<td>0.31</td>
<td>48.9</td>
<td>1.6</td>
<td>3.1</td>
<td>48.3</td>
</tr>
<tr>
<td>Lower Jaw</td>
<td>2.09</td>
<td>13.53</td>
<td>6.47</td>
<td>0.17</td>
<td>0.19</td>
<td>0.30</td>
<td>0.59</td>
<td>318.9</td>
<td>3.8</td>
<td>4.1</td>
<td>107.0</td>
</tr>
<tr>
<td>Ear Canals</td>
<td>1.30</td>
<td>0.60</td>
<td>0.46</td>
<td>0.41</td>
<td>0.31</td>
<td>0.03</td>
<td>0.51</td>
<td>186.4</td>
<td>1.7</td>
<td>4.3</td>
<td>45.0</td>
</tr>
</tbody>
</table>

<sup>1</sup>Part per million
<sup>2</sup>Ca:P ratios were calculated by dividing calcium concentration by phosphorus concentration for each item
<sup>3</sup>Reporting limit: 1 part per million (ppm)
Table 5.3. Descriptions of felids (n=5) observed on days before, during, and after a pig head was offered for four consecutive weeks housed at Omaha’s Henry Doorly Zoo and Aquarium and Blank Park Zoo on Baseline, Enrichment and Post enrichment days from June 30 to July 23, 2014

<table>
<thead>
<tr>
<th>Common name</th>
<th>Scientific name</th>
<th>Sex</th>
<th>Age (years)</th>
<th>Weight (Kg)</th>
<th>Time at zoo (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omaha</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bengal Tiger</td>
<td><em>Panthera tigris</em></td>
<td>Female</td>
<td>9</td>
<td>99.8</td>
<td>91</td>
</tr>
<tr>
<td>Siberian Tiger</td>
<td><em>Panthera tigris altaica</em></td>
<td>Female</td>
<td>9</td>
<td>105.3</td>
<td>31</td>
</tr>
<tr>
<td>Malayan Tiger</td>
<td><em>Panthera tigris jacksoni</em></td>
<td>Female</td>
<td>17</td>
<td>75.3</td>
<td>126</td>
</tr>
<tr>
<td>African Lion</td>
<td><em>Panthera leo</em></td>
<td>Male</td>
<td>15</td>
<td>245.4</td>
<td>150</td>
</tr>
<tr>
<td>Blank Park</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siberian Tiger</td>
<td><em>Panthera tigris altaica</em></td>
<td>Female</td>
<td>17</td>
<td>125.6</td>
<td>182</td>
</tr>
</tbody>
</table>
Table 5.4. Housing specifications for felids (n=5) observed on days before, during, and after a head was offered for four consecutive weeks at Omaha’s Henry Doorly Zoo and Aquarium and Blank Park Zoo on Baseline, Enrichment and Post enrichment days from June 30 to July 23, 2014

<table>
<thead>
<tr>
<th>Common name</th>
<th>Space (m²)</th>
<th>Water</th>
<th>Feed</th>
<th>Feed Amount (Kg)</th>
<th>Access</th>
<th>Style</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Omaha</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bengal Tiger</td>
<td>151.4</td>
<td>Pool</td>
<td>Morning, on exhibit&lt;sup&gt;c&lt;/sup&gt;</td>
<td>4.7</td>
<td>Outdoor</td>
<td>Natural&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
<tr>
<td>Siberian Tiger</td>
<td>49.2</td>
<td>Bowl</td>
<td>Morning, on exhibit</td>
<td>4.9</td>
<td>Indoor</td>
<td>Cement/brick</td>
</tr>
<tr>
<td>Malayan Tiger</td>
<td>111.5</td>
<td>Bowl</td>
<td>Morning, on exhibit</td>
<td>2.3</td>
<td>Indoor and Outdoor</td>
<td>Cement/brick</td>
</tr>
<tr>
<td>African Lion</td>
<td>124.5</td>
<td>Bowl</td>
<td>Morning, on exhibit</td>
<td>4.7</td>
<td>Indoor and Outdoor</td>
<td>Cement/brick</td>
</tr>
<tr>
<td><strong>Blank park</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Siberian Tiger</td>
<td>464.5</td>
<td>Pool</td>
<td>Evening, in back holding&lt;sup&gt;d&lt;/sup&gt;</td>
<td>3.9</td>
<td>Outdoor</td>
<td>Natural</td>
</tr>
</tbody>
</table>

<sup>a</sup> Electronic water bowls: Model 760-10W, Nelson Manufacturing Company, Cedar Rapids, IA, 52404, United States

<sup>b</sup> Access was constant for each felid and never changed throughout the study

<sup>c</sup> Between 0730 and 0900-h in publically viewable enclosure

<sup>d</sup> Between 1700 and 1800-h out of public view

<sup>e</sup> Dirt and grass flooring with logs, rocks, trees, and natural stream/pool in enclosure
Table 5.5. Orts\(^1\), fecal scores\(^2\), and macronutrient intake of felids (n=5) after being offered a pig head at Omaha’s Henry Doorly Zoo and Aquarium and Blank Park Zoo from June 30 to July 23, 2014 and ratios of head composition

<table>
<thead>
<tr>
<th>Orts and Fecal Scores</th>
<th>B</th>
<th>E</th>
<th>P</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orts(^3)</td>
<td>325.21</td>
<td>279.83</td>
<td>23.22</td>
<td>274.83</td>
<td>179.59</td>
<td>17.36</td>
<td>357.00</td>
</tr>
<tr>
<td>Fecal Scores</td>
<td>3.57</td>
<td>3.68</td>
<td>3.68</td>
<td>3.56</td>
<td>3.60</td>
<td>3.79</td>
<td>3.60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Intake from Head Consumption</th>
<th>g</th>
<th>kcats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apparent Intake(^4)</td>
<td>Actual intake(^5)</td>
<td>DM</td>
</tr>
<tr>
<td>Average</td>
<td>630.34</td>
<td>615.91</td>
</tr>
<tr>
<td>Minimum</td>
<td>154.42</td>
<td>150.84</td>
</tr>
<tr>
<td>Maximum</td>
<td>1478.54</td>
<td>1444.39</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Ratios(^6)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Meat:Bone</td>
<td>0.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fat:Bone</td>
<td>0.14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Orts determined by weighing food before offering and re-weighing leftovers 24 hours later
\(^2\) Fecal scores were visually assessed on scale: 1=hard, dry pellets; 2=dry, well-formed; 3=soft, moist, formed; 4=soft, unformed; 5=watery liquid
\(^3\) Orts presented descriptively, not statistically analyzed
\(^4\) Apparent intake of the head was determined by calculating difference between weight of head while frozen, before offering, and 24 hours after offering to felids
\(^5\) Actual grams of intake were calculated by multiplying the apparent intakes by the intrinsic weight losses found (3 kg=2.12%, 3.5 kg=2.32%, 4 kg=2.31%), and subtracting intrinsic weight loss from apparent intake. Macronutrient intakes were calculated by multiplying head macronutrient composition by actual intake amounts (grams)
\(^6\) Meat:bone and fat:bone ratios were determined by manually separating meat and fat from skull bone using hand-held knives. Meat, fat, and skull (including brain) components were then weighed separately to the nearest 0.1 gram
Table 5.6. Ethogram: Description of the large felid behaviors and postures housed at Omaha’s Henry Doorly Zoo and Aquarium, and Blank Park Zoo on Baseline, Enrichment and Post enrichment days from June 30 to July 23, 2014

<table>
<thead>
<tr>
<th>Measure</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Active</strong></td>
<td></td>
</tr>
<tr>
<td>Locomotion</td>
<td>Walking, running, climbing, pacing, jumping in a non-investigatory manner</td>
</tr>
<tr>
<td>Standing</td>
<td>All four feet touching the ground and body held in upright posture</td>
</tr>
<tr>
<td>Rolling</td>
<td>Laying on one side and completely rotating to the other side</td>
</tr>
<tr>
<td>Exploring</td>
<td>Sniffing ground or enclosure features in an investigatory manner (head below shoulders to ground), scratching, licking, or sniffing any part of enclosure</td>
</tr>
<tr>
<td>Grooming</td>
<td>Directing licking or scratching to own body</td>
</tr>
<tr>
<td>Head over water</td>
<td>Head hovering over water or drinking water</td>
</tr>
<tr>
<td>Vocalizing</td>
<td>Making any noise coming from mouth</td>
</tr>
<tr>
<td>Interest in item</td>
<td>Oriented (in same section) towards EE item; sniffing or walking towards, but not touching</td>
</tr>
<tr>
<td>Interaction with item</td>
<td>Any part of the felid is physically touching the enrichment item</td>
</tr>
<tr>
<td>Interest in diet</td>
<td>Oriented (in same section) towards diet; sniffing or walking towards, but not touching</td>
</tr>
<tr>
<td>Interaction with diet</td>
<td>Any part of the felid is physically touching the diet</td>
</tr>
<tr>
<td>Spraying&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Spraying from the posterior for the purpose of scent marking (not urination)</td>
</tr>
<tr>
<td><strong>Inactive</strong></td>
<td></td>
</tr>
<tr>
<td>Laying</td>
<td>Laying down and immobile</td>
</tr>
<tr>
<td>Sitting</td>
<td>Front legs extended and back legs bent with posterior on ground</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
</tr>
<tr>
<td>Eliminatory&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Any projection of bodily fluids i.e. urination, defecation</td>
</tr>
<tr>
<td>Other</td>
<td>Observer could not see the felid</td>
</tr>
</tbody>
</table>

<sup>a</sup>All behaviors were mutually exclusive per scan. The ethogram was adapted from (Skibiel et al., 2007) and (Wells and Egli, 2004).

<sup>b</sup>Spraying was distinguished from eliminatory behaviors (which was defined as regular urination and defecation) as being spraying of objects for scent marking purposes, not steady urination.
Table 5.7. Descriptive average percentage of time five large exotic felids spent engaging in mutually exclusive behaviors and postures on Baseline, Enrichment, and Post enrichment days for four consecutive weeks housed at Omaha’s Henry Doorly Zoo and Aquarium and Blank Park Zoo from June 30 to July 23, 2014.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Day, %</th>
<th></th>
<th>Week, %</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B</td>
<td>E</td>
<td>P</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td><strong>Active</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standing</td>
<td>4.23</td>
<td>3.12</td>
<td>3.21</td>
<td>4.02</td>
<td>3.09</td>
<td>3.65</td>
<td>3.31</td>
</tr>
<tr>
<td>Rolling</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Exploring</td>
<td>1.42</td>
<td>0.87</td>
<td>1.33</td>
<td>1.38</td>
<td>1.10</td>
<td>1.58</td>
<td>0.76</td>
</tr>
<tr>
<td>Grooming</td>
<td>4.78</td>
<td>4.32</td>
<td>3.08</td>
<td>3.92</td>
<td>3.53</td>
<td>4.75</td>
<td>4.20</td>
</tr>
<tr>
<td>Head over water</td>
<td>0.51</td>
<td>1.01</td>
<td>0.51</td>
<td>0.88</td>
<td>0.83</td>
<td>0.34</td>
<td>0.55</td>
</tr>
<tr>
<td>Vocalizing</td>
<td>0.83</td>
<td>0.46</td>
<td>0.60</td>
<td>0.33</td>
<td>0.66</td>
<td>0.76</td>
<td>0.83</td>
</tr>
<tr>
<td>Interest in item&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.09</td>
<td>0.09</td>
<td>0.09</td>
<td>0.11</td>
<td>0.00</td>
<td>0.07</td>
<td>0.21</td>
</tr>
<tr>
<td>Interaction with item&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.05</td>
<td>17.95</td>
<td>0.18</td>
<td>5.73</td>
<td>4.57</td>
<td>7.78</td>
<td>6.61</td>
</tr>
<tr>
<td>Interest in diet</td>
<td>0.12</td>
<td>0.00</td>
<td>0.30</td>
<td>0.21</td>
<td>0.07</td>
<td>0.28</td>
<td>0.00</td>
</tr>
<tr>
<td>Interaction with diet</td>
<td>3.42</td>
<td>2.18</td>
<td>3.36</td>
<td>2.82</td>
<td>2.96</td>
<td>3.03</td>
<td>3.21</td>
</tr>
<tr>
<td>Spraying</td>
<td>0.00</td>
<td>0.05</td>
<td>0.00</td>
<td>0.00</td>
<td>0.06</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Inactive</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Laying</td>
<td>64.54</td>
<td>50.28</td>
<td>63.73</td>
<td>58.83</td>
<td>66.39</td>
<td>46.63</td>
<td>64.67</td>
</tr>
<tr>
<td>Sitting</td>
<td>0.78</td>
<td>0.28</td>
<td>0.28</td>
<td>0.17</td>
<td>0.28</td>
<td>0.55</td>
<td>0.90</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Eliminatory</td>
<td>0.28</td>
<td>0.23</td>
<td>0.37</td>
<td>0.17</td>
<td>0.44</td>
<td>0.28</td>
<td>0.28</td>
</tr>
<tr>
<td>Other</td>
<td>0.09</td>
<td>0.14</td>
<td>0.05</td>
<td>0.06</td>
<td>0.11</td>
<td>0.14</td>
<td>0.07</td>
</tr>
</tbody>
</table>

<sup>a</sup> Enrichment item on Baseline (B) and Post enrichment (P) days was zoos environmental enrichment devices provided per standard operating procedure; on Enrichment (E) days the enrichment item was the head. Interest was defined as oriented towards, but not touching while interaction was defined as felid physically touching the object.
Figure 5.1. Section locations of enclosures of large exotic felids housed at Omaha Henry Doorly Zoo and Aquarium and Blank Park Zoo.
Figure 5.2. LSMeans (±SE) percentage of time large felids engaged in active¹ (Locomotion, Standing, Rolling, Exploring pen, Grooming, Head over water source, Vocalizing, Interest in item, Interaction with item, Interaction with diet, Interest in diet, and Spraying), inactive² (Laying and Sitting), and other³ (Eliminatory and Other) behaviors and postures on Baseline, Enrichment and Post enrichment days over 4 consecutive weeks. Numbers lacking common superscript letters (a-c) are statistically different at P<0.0001.
Figure 5.3. LSMMeans (±SE) percentage of time large felids engaged in active\(^1\) (Locomotion, Standing, Rolling, Exploring pen, Grooming, Head over water source, Vocalizing, Interest in item, Interaction with item, Interaction with diet, Interest in diet, and Spraying), inactive\(^2\) (Laying and Sitting), and other\(^3\) (Eliminatory and Other) behaviors and postures over four consecutive weeks. Weeks consists of one Baseline, one Enrichment, and one Post-enrichment day. Numbers lacking common superscript letters (a-c) are statistically different at P<0.0001.
Beef and horsemeat comprise the majority of raw meat diets for carnivores managed in zoological institutions. A pork-based diet is typically not fed and has not been evaluated in felids, largely because of microbial and parasitic concerns. These concerns have been mitigated in the past several decades, however, through improved farm management and microbial interventions (Farkas, 1998; Ricke, 2003; Rastogi et al., 2007; Greve, 2012). The zoo industry could benefit from another dietary option to avoid neophobia (Bradshaw, 2006) and, in turn, make the job of animal managers easier. Pork producers also have been looking for avenues that add value to their products (NPB, 1999; Buhr, 2004) while avoiding the expense of sending by-products to rendering. The formulation of a raw pork-based diet satisfies the need of dietary variety that zoos desire while simultaneously providing pork producers with an outlet to add value to their by-products.

Zoos have been feeding raw meat diets for many years, and microbial populations in those diets has been a concern in the past. Still, however, there is a paucity of research looking at what microbial levels are acceptable and safe in these diets for specific species. Another concern with commercially prepared raw meat diets is that they do not fulfill the nonnutritive requirements of felids. While all nutritional requirements may be met by these diets, requirements such as masticatory, psychological, and oral needs associated with dietary consumption are not (Lindburg, 1988). Failure to meet these nonnutritive needs can lead to health and behavioral issues. Zoos often look for effective and practical enrichment to avoid these problems.
Items that pork producers often send to rendering, such as various bones, snouts, and heads have potential for use as enrichment items for captive felids. When offering enrichment that is consumable, it is important to assess the nutritional contribution of that item to avoid over nutrition. Our overall objectives were to evaluate the use of pork and pork by-products in diets and environmental enrichment used for captive exotic felids.

Our first aim (chapter 3) was to evaluate the influence of pork and pork-by products on macronutrient digestibility, fecal scores, and palatability, compared to standard zoological carnivore diets, in large captive exotic felids. We found that a pork-based diet was similarly, and in some cases more digestible than beef- or horse-based raw meat diets. Apparent digestibilities of DM and CP were higher (P<0.05) in cats fed Pork (87.97 and 95.74%) compared with cats fed Horse (83.59 and 92.71%) and B2 (85.60 and 93.14%). Apparent OM digestibility was higher (P<0.05) in cats fed Pork (90.76%) than cats fed Horse (88.53%). Apparent fat digestibility values were higher (P<0.05) in cats fed Pork (98.51%) compared with cats fed B1 (95.51%) or B2 (96.45%). GE digestibility values were higher in cats fed Pork (92.38%) compared with B1 (90.21%). Fecal scores in felids fed the Pork diet (2.94) were also closest to ideal compared to Horse (2.30), B1 (3.42), and B2 (3.54). We also found that a pork-based diet was palatable to large exotic felids. The pork diet was selected in 24 of 37 total (64.86%) observations of first approached and 23 out of 33 total (69.70%) observations for first tasted, when compared to a beef-based diet.

The second aim of our research (chapter 4) was to evaluate the influence of pork and pork-by products on macronutrient digestibility and fecal scores, compared to standard zoological carnivore diets, in small captive exotic felids, as well as evaluate microbial populations in commercially available raw meat diets. Results showed that the Pork diet was
very similarly digested, in African wildcats, compared to a horse-, beef-, or horse/beef blend-based diet. The only statistical difference seen between the Pork diet and other diets was digestibility of OM being higher (P<0.05) when cats consumed the Blend diet (97.15%) compared to the Pork diet (93.10%). The Pork diet also was not numerically the least digestible in any nutrient evaluated. The results of our large and small cat digestibility studies support the conclusion that a raw pork-based diet is well utilized by exotic felids and can be included among dietary options in a managed setting.

We found microbial counts to be variable between the four diets (E. Coli: 110 to 10,000 cfu/g; total coliforms: 150 to 28,000 cfu/g; yeast: 20 to 4,000 cfu/g; mold count: not detectable to 10 cfu/g; aerobic plate count: 23,000 to 26,000,000 cfu/g). Staphylococcus aureus was not detected in any of the diets and Salmonella was presumptive positive in the Pork and Blend diet, and negative in the other two diets. While these population counts are much higher than regulations placed on human grade food (Salmonella absent in 10 grams of product, E. Coli <500 cfu/g, and aerobic colony count <5x10^6 cfu/g (EC, 2005)), no clinical signs of illness were documented in felids consuming these diets throughout the research. These results suggest that microbial load recommendations should be less strict than human grade food regulations.

Finally, our third aim (chapter 5) was to evaluate pork-based by-products for chemical and mineral composition and to determine if a pig head was biologically relevant environmental enrichment for captive large exotic felids. Chemical analysis revealed by-products ranged widely in composition: DM: 26.01-71.23%; OM: 53.04-96.79%; CP: 22.90-79.29%; fat: 22.01-63.15%; CF: 0.25-19.54%; TDF: 0.04-3.44%; GE: 3.73-7.45 kcal/g among all 11 items. This range provides options for animal managers when looking to
provide consumable environmental enrichment to meet nonnutritive needs, while still balancing nutrient intake. The results from behavioral observation of large felids offered a pig head as enrichment show that this enrichment item does increase active behaviors (by 55.70 and 26.42% compared to before and after offering the head, respectively). Other data collected, including orts, fecal scores, number of location changes, and time to approach enrichment, suggest that this enrichment device maintains its novelty over 4 weeks, while not negatively affecting diet consumption or intestinal health. Felids used in this study were of varying ages and sizes, making results robust and possibly applicable to a wide range of animals housed in captivity.

This behavioral research has answered many questions, but plenty more remain. We hypothesize the use of pig heads as enrichment items will help reduce the occurrence of stereotypies; however, this should be tested directly. Behavioral impacts of altering the placement and offering schedule of the enrichment item should also be evaluated. The use of the other ten items analyzed in our study should also be evaluated for their use as environmental enrichment and/or dietary components. Furthermore, behavioral research, similar to our study, should be carried out using small cat species to see if similar behavioral changes occur as did in large felid species. Visitor perspective and interest is another area that should be considered. Surveys and observational studies on visitor interest and amount of time spent at exhibits in which animals are being enriched is an area for future research.

While the current research has made positive strides in the area of comparative and exotic animal nutrition, more research is needed in this field. In both digestibility studies (large and small cats), calculated metabolizable energy (ME) values were found to underestimate kcals from the diets. This is likely because of calculation methods being based
on digestibility of kibble diets. It has been shown that raw meat diets are much more digestible than kibble diets fed to felids, and this underestimation of kcals of ME may lead to over feeding. More research is needed to determine appropriate ME calculation methods for raw meat diets fed to captive felids. Potential of pork, as a novel protein source, to mitigate or remedy food allergies and sensitives as well as colitis and irritable bowel syndrome should also be further investigated. Additionally, further research should be conducted to evaluate application of a pork-based for other managed carnivorous species including birds of prey and canids. The overall effects of dietary variety for captive exotic felids also should be a considered area of research. Overall, we conclude that pork is a viable dietary protein option for managed exotic felids.

Literature Cited


NPB, 1999, Case studies of value added pork production & marketing, National Pork Board.
