NUTRITIONAL EVALUATION OF RAW MEAT AND WHOLE PREY DIETS FOR DOMESTIC AND EXOTIC CATS

BY

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DISSERTATION

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ABSTRACT

For captive exotic felids, the predominant diet types fed are raw meat-based and whole prey diets. These diet types are not the most common fed to domestic cats, but there has been increased interest in feeding alternative diet types, including raw and whole prey diets. There is a paucity of peer-reviewed literature examining nutrient composition, apparent total tract macronutrient digestibility, and bioavailability of raw meat-based and whole prey diets in felids. A majority of research pertaining to raw diets has focused on raw beef- and horsemeat-based diets, with little research focused on alternative protein sources (e.g., other species, whole prey diets) or other dietary ingredients (e.g., fiber sources and concentrations, micronutrients).

The overall objective of this research was to evaluate raw meat and whole prey diets for use by domestic and captive exotic cats, including diet compositional analyses, and effects on blood metabolites, nutrient digestibility, N metabolism, microbiota composition, and fermentative end-products. Our first aim was to evaluate traditional (beef; horse) and alternative (bison; elk) protein sources for use in raw meat-based diets for captive exotic and domestic felids. Our second aim was to evaluate common fiber types and concentrations utilized in raw meat-based diets for captive exotic felids. We evaluated cellulose and beet pulp as fiber sources at 2 or 4% of the diet. Our third aim was to determine nutrient composition and digestibility of common whole prey items fed to captive exotic felids. Firstly, we compared apparent total tract macronutrient digestibility of whole-prey chicks, whole ground chicken, a chicken-based canned diet, and a chicken-based extruded diet. Our final study was performed to determine the nutrient composition of 20 commercially available protein sources used in raw meat-based and whole prey diets.

In general, all diets were well utilized by all exotic and domestic felids, regardless of protein source, fiber type and concentration, or processing method. All animals were able to maintain body condition while being fed these raw meat-based or whole prey diets. Additionally, when fed raw meat-based, whole prey, or traditional canned or extruded diets, domestic cats maintained body weight (BW), N balance, and the majority of blood metabolites within reference ranges.

In our first aim, we determined that traditional (beef trimmings; horse trimmings) and alternative (elk meat; bison trimmings) protein sources utilized in raw-meat based diets containing cellulose had high apparent total tract organic matter (OM) and crude protein (CP) digestibility (>85% and > 95%, respectively) in domestic and captive exotic cats, high standardized amino acid digestibility in roosters (total essential amino acid digestibility > 90%), and high amino acid scores (81 to 95). We also determined that while all raw meat-based diets were adequate sources of α-linolenic acid, none met the recommended levels of linoleic acid (NRC, 2006). Additional deficiencies were observed in total fat, EPA, DHA, and arachidonic acid concentrations.

For our second aim, we demonstrated that increasing the inclusion of cellulose (2 vs. 4%), a non-fermentable fiber source, in place of beef trimmings, in the diets of captive exotic species decreased ($P \leq 0.05$) apparent total tract OM digestibility (86% vs. 80%) without impacting apparent total tract CP digestibility (95%). Inclusion of beet pulp, a fermentable fiber, however, did not decrease apparent total tract OM digestibility (85 to 87%), but decreased ($P \leq 0.05$) apparent total tract CP digestibility (93%) compared to cats fed cellulose (95%). Additionally, apparent total tract dry matter (DM), OM, fat, and gross energy digestibility decreased ($P \leq 0.05$) linearly with BW independent of fiber type. Apparent total tract CP

digestibility decreased ($P \leq 0.05$) linearly with BW when exotic cats were fed beet pulp, but not when fed cellulose. Exotic cats fed diets containing beet pulp had decreased ($P \leq 0.05$) fecal pH and fecal DM, and increased ($P \leq 0.05$) fecal score, fecal volume, and fecal short- and branched-chain fatty acids, and ammonia concentrations compared to cats fed diets containing cellulose.

In the first study of our third aim, we observed that when comparing apparent total tract OM digestibilities in traditional canned (86 to 87%) and extruded (86 to 88%) diets, whole ground chicken excluding feathers was highly digestible (94%), while whole 1 to 3 d-old chicks had lower digestibility (83 to 85%). In the final study, we observed that all whole prey contained adequate concentrations of CP, and a majority had adequate concentrations of amino acids; however, taurine concentrations were low in whole prey rabbits. Additionally, a majority of whole prey samples had mineral (K, Na, Cl, Mg, Cu, Mn, Zn) concentrations below AAFCO (2012) recommendations for domestic cats.

Zoo staff and owners have a responsibility to provide proper nutrition of animals in their charge by supplying the dietary nutrients necessary for cellular repair, growth, and health management; however, the ability of raw meat-based and whole prey diets to meet feline nutrient requirements has been understudied. This research identified important deficiencies in essential fatty acids, minerals, and amino acids in whole prey and raw meat ingredients. Additionally, we elucidated the role of fiber type and concentration in raw meat-based diets of domestic cats and large and small exotic felids. Undoubtedly, the investigations herein uncovered differences in composition and digestibility that will have important implications for diet formulation in domestic and captive exotic felids.

I dedicate this dissertation to my family.

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LIST OF ABBREVIATIONS

Item	Meaning
AA	Amino acid
AAFCO	American Association of Feed Control Officials
AAS	Amino acid score
ALP	Alkaline phosphatase
ALT	Alanine aminotransferase
ARA	Arachidonic acid
AWC	African wildcat
BCFA	Branched-chain fatty acids
BCS	Body condition score
BE	Beef-based diet
BI	Bison-based diet
BP	Beet pulp-containing diet
BW	Body weight
C	Cellulose-containing diet
CAN	Chicken-based canned diet
CFU	Colony forming units
CLA	Conjugated linoleic acid
CP	Crude protein
CVM	Center for Veterinary Medicine

Item	Meaning
DE	Digestible energy
DHA	Docosahexaenoic acid
DM	Dry matter
DMI	Dry matter intake
DOM	Domestic cat
DWI	Dietary water intake
E	Elk-based diet
EFA	Essential fatty acids
EPA	Eicosapentaenoic acid
EXT	Chicken-based extruded diet
F	Female
FAME	Fatty acid methyl ester
GE	Gross energy
GRO	Whole ground chicken diet
H	Horse-based diet
JAG	Jaguar
LA	Linoleic acid
LAA	First limiting amino acid
LL	α linolenic acid
M	Male
ME	Metabolizable energy
MT	Malayan tiger

Item	Meaning
MUFA	Monounsaturated fatty acids
NA	None available
ND	None detected
NEFA	Non-esterified fatty acids
NRC	National Research Council
OM	Organic matter
OMD	Organic matter disappearance
PDCAAS	Protein digestibility corrected amino acid score
PUFA	Polyunsaturated fatty acid
SCFA	Short-chain fatty acids
SEM	Standard error of the means
SFA	Saturated fatty acids
ST	Siberian tiger
TAA	Total amino acid
TDF	Total dietary fiber
TEAA	Total essential amino acids
TFA	Total fatty acids
TNEAA	Total non-essential amino acids
WHO	Whole chick diet

CHAPTER 1: INTRODUCTION

Felids are obligate carnivores, and evolutionary influence of a strictly carnivorous diet has resulted in specialized metabolic pathways and nutritional requirements. In the wild, animal tissue provides all nutrients required by felids (Morris, 2002). Compared to omnivores, felids have evolutionarily lacked the need for rapid adaptation to a variety of diet types and are metabolically prepared for high metabolism of proteins and fat, with less emphasis on utilization of carbohydrates. As a result, felids have many unique dietary requirements including high protein, taurine, and tyrosine requirements, and an obligate requirement for arginine. The nutrient requirements of felids, especially these nutritional idiosyncrasies, have been well defined for domestic cats (*Felis catus*; NRC, 2006); however, nutrient requirements of captive exotic felids have not been adequately explored.

In captivity or in a home setting, a felid's diet is provided solely by the zoo or owner, respectively. For captive exotic felids, the predominant diet types fed are raw meat-based and whole prey diets. Feeding these diet types is not usual in domestic cats, but there has been an increased popularity in feeding alternative diet types, including raw and whole prey diets, recently. Zoo staff and owners have a responsibility to provide the nutrients necessary for cellular repair, growth, and health management; however, the ability of raw meat-based and whole prey diets to meet the feline nutrient requirements has been understudied.

There is a paucity of peer-reviewed literature examining nutrient composition, apparent total tract macronutrient digestibility, and bioavailability of raw meat-based and whole prey diets in felids. A majority of research pertaining to raw diets has focused on raw beef- and horsemeat-based diets, with little research focused on alternative protein sources (e.g., other species, whole prey diets) or other dietary ingredients (e.g., fiber sources and concentrations, micronutrients).

Undoubtedly, investigations in these areas will uncover differences in composition and digestibility, with implications for diet formulation domestic and captive exotic felids.

In addition to proximate analysis, protein quality, and essential fatty acid, mineral, and vitamin concentrations are of interest. The examination of commercially available alternatives, including raw meat sources, whole prey items, and fiber sources will provide important data regarding their interactions and effects on dietary composition, macronutrient digestibility, and bioavailability.

The overall objective of this research was to evaluate raw meat and whole prey diets for use in domestic and captive exotic cat diets, including diet compositional analyses and effects on blood metabolites, nutrient digestibility, N metabolism, and fermentative end-products.

Our first aim was to evaluate traditional (beef; horse) and alternative (bison; elk) protein sources for use in raw meat-based diets for captive exotic and domestic felids. Diets were analyzed for nutrient composition, including amino acid and fatty acid concentrations, and protein quality was assessed using the cecectomized rooster assay. Nitrogen metabolism and fecal fermentative end-product concentrations were examined in the domestic cat, and apparent total tract macronutrient digestibility was determined in the domestic cat and three captive exotic cat species.

Our second aim was to evaluate common fiber types and concentrations utilized in raw meat-based diets for captive exotic felids. We evaluated cellulose and beet pulp as fiber sources, each at 2 or 4% of the diet. We examined apparent total tract macronutrient digestibility and fecal fermentative end-products in four captive exotic cat species.

Our third aim was to determine nutrient composition and digestibility of common whole prey items fed to captive exotic felids. Firstly, we compared apparent total tract macronutrient

digestibility of whole-prey chicks, whole ground chicken, a chicken-based canned diet, and a chicken-based extruded diet in African wildcats and domestic cats. In addition to nutrient digestibility measurements in domestic cats, we also measured blood metabolites and fecal-fermentative end-products. Our final study was performed to determine the nutrient composition of 20 commercially available protein sources used in raw meat and whole prey diets. Diets were analyzed for macronutrient, amino acid, and mineral concentrations.

CHAPTER 2: LITERATURE REVIEW

Of the 36 extant non-domestic felid species, 16 are endangered/threatened (US Fish and Wildlife Services, 2012). They are a diverse group of species, exhibiting a wide range of body weights (2.5 to >250 kg), behaviors, and dietary habits. Felids are obligate carnivores, and evolutionary influence of a strictly carnivorous diet has resulted in specialized metabolic pathways and nutritional requirements. Felids are euphagous, primarily feeding on one to a few species of prey for a majority of their meals, but opportunistically eat 20-30 prey species (Lindburg, 1988).

In the wild, animal tissue provides all nutrients required by felids (Morris, 2002). The digestive tracts of felids are composed of a simple stomach, short digestive tract, and well developed canine and carnassiate teeth for tearing and gripping flesh. Thus, they are physically adapted to highly digestible animal prey diets (Kendall et al., 1982).

Energy density and nutritional quality of carnivorous prey is relatively constant (Morris et al., 2006). Animal prey are compositionally high in protein and low in carbohydrate. For example, the composition of the white-footed mouse (*Peromyscus leucopus*) is 60% crude protein (CP) and 20% fat on a dry matter (DM) basis (Powers et al., 1989). Compared to omnivores, felids have evolutionarily lacked the need for rapid adaptation to a variety of diet types and are metabolically prepared for high metabolism of protein and fat, with less emphasis on utilization of carbohydrate. As a result, felids have many unique dietary requirements, including high protein, taurine, and tyrosine requirements, and an obligate requirement for arginine. The nutrient requirements of felids, especially these nutritional idiosyncrasies, have been well defined for domestic cats (*Felis catus*; NRC, 2006); however, nutrient requirements for captive exotic felids have not been adequately explored. Because of this, nutrient

requirements of domestic cats are used as the primary benchmark for captive exotic felids. While nutritional idiosyncrasies similar to those of domestic cats have been examined (Davidson et al., 1986; Howard et al., 1987; Ofri et al., 1996; Bauer, 1997), to our knowledge there are no studies that have determined specific dietary requirements for captive exotic species, and only one peer-reviewed article comparing nutrient digestibility in domestic cats to large exotic felids fed the same diet (Vester et al., 2010a). Further research examining the use of the domestic cat as a model for captive exotic felids is warranted.

Wild felines eating live prey and domestic cats fed nutritionally complete foods have little need to select between foods based on nutritional content. In captivity or in a home setting, a felid's diet is provided solely by the zoo or owner, respectively. Thus, there is a responsibility to provide the nutrients necessary for cellular repair, growth, and health management. For captive exotic felids, the predominant diet types fed are raw meat-based and whole prey diets. These diet types are not the most common fed to domestic cats, but there has been an increase in popularity in alternative diet types, including raw and whole prey diets recently. There are advantages and disadvantages associated with different diet types and the one chosen might not always meet the requirements of the animal. Methods to test nutritional adequacy of a pet food include: monitoring body weight, body condition, physical activity level, complete blood cell counts, and serum chemistry profiles; measuring blood taurine concentration; observations of skin and hair color and texture; evaluation of the lens and retina of the eye; and stool quality (Remillard, 2008). The diet itself must also be examined, with a focus on the nutrient content of the raw materials, special requirements of the animal, and the influence of processing methods on the bioavailability of the chemical components. However, there is a paucity of peer-reviewed literature examining raw meat and whole prey diets.

Feeding Captive Exotic Felids Raw Meat and Whole Prey

The predominant diet types fed to captive exotic felids are raw meat supplemented with vitamins and minerals, raw meat-based commercial diets, and whole prey. Because raw meat and whole prey diets may increase risk of bacterial contamination in the zoo setting (Clyde et al., 1997; Crissey et al., 2001), extruded diets have been used as an alternative option for small exotic felids (Crissey et al., 1997; Vester et al., 2010b). In the US, commercial raw meat-based diets (Pearson et al., 2005) are the main diet type fed. Feeding of whole prey in zoos, although controversial in the US, is common for both nutritive and enrichment purposes. Pearson et al. (2005) surveyed US and European zoos (51 respondents) and reported that ~20% of US zoos and ~85% of European zoos fed whole prey as the predominant diet type or on a weekly basis to their carnivores. Although the behavioral and ethical implications of different diet types have been widely discussed, there is a paucity of information on the nutritive value of many of the various dietary options.

Raw Meat Diets

Raw meat diets are primarily formulated using the nutrient requirements of domestic cats. Observations of wild felids also are utilized for diet formulation, including feeding habits, scat analysis, and composition of prey. However, composition of prey species is rarely determined, and observations of feeding habits and scat analysis can be of limited use without determination of prey composition. Digestibility trials in captive exotic species, when possible, are also important benchmarks.

Raw meat diets for captive exotic felids are most often formulated to use meat trimmings. These sources contain excess connective and other tissues after slaughter that are highly variable and can be high in fat. The resulting diets also are highly variable in nutrient composition. For

example, reported dietary DM, CP, and fat for such diets fed to exotic species ranged from 29 to 40%, 38 to 84%, and 8 to 38%, respectively (Barbiers et al., 1982; Hackenburger and Atkinson, 1983; Wynne, 1989; Crissey et al., 1997; Edwards et al., 2001, 2007; Bechert et al., 2002).

Digestibility of raw meat-based diets appears to depend on species and total dietary fiber (TDF) content (Clauss et al., 2010); however, few interactions have been reported between diet and species for diet digestibility (Vester et. al., 2010a). Not surprisingly, reported values for apparent total tract digestibility are also highly variable [DM: 66 to 89%, CP: 73to 96%, fat: 73 to 99% (Barbiers et al., 1982; Wynne, 1989; Crissey et al., 1997; Edwards et al., 2001; Vester et al., 2008; 2010a; 2010b)]. The ability of zoological parks to obtain digestibility data can be limited by the number of animals and species available for trials, and housing conditions. Natural exhibits and group housing situations decrease the ability to accurately measure food intake and fecal output. Because of these limitations, there is an overall lack of peer-reviewed research in these species, and a need for research examining commercially available alternatives to raw horse- and beef-based diets exists.

Whole Prey Diets

In the zoo setting, whole prey carcasses are often fed as enrichment, with the aim of encouraging species-typical behavior, specifically increasing the time and energy spent finding and consuming food. In the wild, felines spend a large portion of their time on feeding activity (i.e., locating, capturing, killing, and eating prey). Feeding whole prey has been reported to increase diversity and amount of feeding behaviors (feeding duration, exploring, and processing) and decrease stereotypic behaviors (Lindburg and Bond, 1990; Shepardson et al., 1993; Ziegler, 1995). For example, when a female fishing cat was provided with live fish, there were increases ($P < 0.05$) in predation behaviors (40% increase) and diversity of behaviors exhibited

(Shepardson et al., 1993). Additionally, there may be implications for increased chewing for oral health due to increased abrasion and exercise of mastication (Lindburg and Bond, 1990). A large portion of data on whole prey is from anecdotal, unpublished, or non-peer reviewed sources (Powers et al., 1989), and primarily focus on these non-nutritive benefits. Data on the nutrient composition, digestibility, and bioavailability of commercially available whole prey species is lacking.

Reported nutrient composition of commonly fed whole prey (i.e., mouse, rat, guinea pig, rabbit, quail, chicken) are variable. Variation in nutrient composition of whole prey can result from differences in diet, genetics, age, sex, or an interaction among these variables (Douglas et al., 1994; Dierenfeld et al., 1996; Clum et al., 1997). Ranges of average nutrient composition for these species are: 58 to 82 % moisture; 40 to 70% CP; 5 to 47% fat, and 7 to 15% ash (Davidson et al., 1978; Barton and Houston, 1980; Litvaitis and Mautz 1980; Stalmaster and Gessaman, 1982; Ball and Golightly, 1992; Douglas et al., 1994; Dierenfeld et al., 1996; Clum et al., 1997; Fekete et al., 2001). Because of this variation, species-specific differences are not readily predictable. For example, nutrient composition ranges reported for mice only are: 58 to 82% moisture; 40 to 64% CP; and 14 to 47% fat. This variation can be partially explained by age/size. As mice age, moisture concentrations decrease from 82% (pinky) to ~70% (fuzzy, crawler, small and medium), and fat concentrations increase from 15% (pinky) to 47% (fuzzy and crawler) and subsequently decrease with age to ~20% (small and medium). A majority of research has focused on laboratory rats and mice. Proximate, mineral, and vitamin composition of rodents have been examined and compared for differences in age and species (Douglas et al., 1994; Dierenfeld et al., 1996; Clum et al., 1997). Few in-depth examinations of nutrient composition in other species have been done (Clum et al., 1997; Davidson et al., 1978). Even for

well-studied species (i.e., mouse), gaps in the knowledge exist, such as the nutrient composition of prey obtained frozen from a supplier compared to those raised on-site.

Few studies have examined the digestibility of whole prey items by captive exotic felids (Golley et al., 1965; Bennett et al., 2010). Davidson et al. (1978) compared apparent total tract digestibility in fishers fed deer meat, whole hare, whole quail, or a small whole mammal mix (73% vole, 16% shrew, 11% mouse). Total tract DM digestibility was highest ($P < 0.05$) for fishers fed deer (92%), and higher ($P < 0.05$) in fishers fed quail (82%) or hare (86%) as compared to those fed the small mammal diet (73%). Gross energy digestibility was higher ($P < 0.05$) for fishers fed deer (93%), quail (91%), and hare (91%) as compared to those fed the small mammal diet (81%). Poor DM digestibility of whole prey diets may have been due to the higher ash contents of the whole prey (8 to 15%) compared to deer meat (3.5%). Additionally, the proportionately higher skin, fur, and bone content of the small mammal diet may have reduced the GE digestibility. Bedford and Christian (2000) reported that hair accounted for 2 to 7 percentage units of GE digestibility in pythons fed mice. Litvaitis and Mautz (1980) reported total tract DM and GE digestibilities for coyotes fed mice (83% and 91%) were similar to those fed hare (82% and 88%), and Fekete et al. (2001) reported similar apparent total tract digestibility values for ground, heat-treated, and whole rat fed to domestic cats (81% DM digestibility), indicating that further research is necessary in captive exotic species. Crude protein and fat digestibilities of the whole prey items in fishers also were affected by whole prey species/proximate composition and ranged from 79 to 93% and 81 to 99%, respectively (Davidson et al., 1978).

Raw Meat and Whole Prey Diets for Domestic Felids

There are a multitude of diet options for a pet owner to choose from, including commercially available extruded and canned diets that are more traditional, unconventional diets (e.g., vegetarian, natural, organic, and raw diets) that have recently increased in popularity, and homemade diets such as raw meat-based and whole prey diets. Often, cat owners feed unconventional and homemade diets because of concerns about additives, preservatives, and contaminants; distrust of pet food companies due to a misunderstanding/inability to understand pet food labels; or need to address a medical condition. In a phone survey of 469 cat owners, 95.5% fed $\geq$ 75% commercial food to their pet, while 2.7% fed $\geq$ 50% non-commercial food (Michel et al., 2008). Surveyed cat and dog owners were asked to provide their attitude towards a statement given a 5-point scale with 1=strongly agree to 5=strongly disagree. Significant differences between non-commercial and commercial feeders on the processing and commercial foods were reported. Non-commercial feeders responded more negatively ($P<0.05$) towards statements on processing and cooking of pet foods, trust in manufacturers, concentrations of meat and additives in commercial foods, and the wholesomeness and nutritional adequacy of commercial pet foods.

Recent pet food recalls and widespread media coverage may increase owner mistrust of pet food companies. Three recent large pet food recalls have included traditional diet types. In December 2005, Diamond Pet Foods recalled pet foods due to contamination of aflatoxin. In April 2006, diets containing toxic levels of vitamin D were recalled by Royal Canin. And most recently, in March 2007, Menu Foods, Inc. recalled foods due to contamination with melamine. The melamine contamination involved many manufacturers and diets. In two of these cases, nutritional adequacy of the diets was sound, but inadvertent inclusion of toxins made the foods

unsafe. In the melamine case, the criminal adulteration with inclusion of the compound made the foods unsafe.

Much of the rationale for feeding raw meat and whole prey diets are based on the cat's evolutionary history as a carnivore. Additionally, many people who feed raw meat diets believe that heat processing may decrease some of the nutritional benefits in the food, including heat-labile nutrients such as thiamin, and potentially destroying functional proteases present in the raw meat (Freeman and Michel, 2001; Berschneider, 2002). Owners who feed raw diets anecdotally claim that they improve coat color and quality, increase physical activity levels, improve behavior, improve health and immune function, and reduce incidence of allergies, arthritis, pancreatitis, and parasites (Freeman and Michel, 2001). The benefits of raw meat and whole prey diets have not been substantiated by well-designed research trials, and there are many potential risks to feeding raw meat, including health problems that arise from inclusion of feeding raw bones, potential for nutritional inadequacy, and bacterial contamination present in most raw meats. Research regarding the risks and disadvantages of raw meat diets also is lacking.

Specifically, little research has been done on composition or digestibility of raw meat diets for pets, and most has focused on diets for domestic dogs (Freeman and Michel, 2001; Berschneider, 2002). Kendall et al. (1982) compared apparent total tract digestibility of mincemeat, canned cat food, and dry cat food diets. Dry matter, CP, and fat digestibilities were highest ($P < 0.05$) in mincemeat diets (95%, 96%, and 96%, respectively) as compared to canned (76 to 79%, 81 to 83%, and 78 to 85%, respectively) and dry foods (68%, 77%, and 56%, respectively). Dry matter and fat digestibilities were also higher ($P < 0.05$) in cats fed canned as compared to dry diets. Kerr (2010) also reported higher ($P < 0.05$) apparent total tract DM, CP,

and fat digestibilities of a raw beef-based diet (87%, 93%, and 96%, respectively) as compared to a dry chicken-based diet (78%, 82%, and 91%, respectively); however, the digestibility values of the dry diet reported by Kerr (2010) were higher than those reported by Kendall et al. (1982). These differences may be related to advances in pet food formulation, and it is probable that more recent formulations for canned diets also may have increased digestibility. Nott et al. (1994) examined canned diet utilized by cats and reported 85 to 90% DM, 88 to 90% CP, and 96% fat digestibilities. The authors are aware of two studies that have reported digestibility data of ground whole prey in domestic cats (Fekete et al., 2001; 2004), but none that have compared whole prey to other diet types. These studies, however, utilized ground whole prey as a basal diet, and provided little information as it pertained to the diet itself (i.e., source, age of prey, body parts included). Apparent total tract DM, CP, and fat digestibilities reported for ground, heat-treated rat were 81%, 85%, and 99%, respectively (Fekete et al., 2001), and were 85%, 94%, and 99%, respectively, for ground chicken carcass (Fekete et al., 2004).

Pet owners are have the same data available to them as do zoos, and may be further limited due to reduced access to literature and diet formulation software. Further research is needed to highlight the advantages and disadvantages of raw meat and whole prey diets, and to provide adequate resources for home feeders.

Implications of Feeding Raw Meat and Whole Prey Diets for Nutrient Requirements

Animal protein sources can be important sources of essential and nonessential amino acids, fatty acids, vitamins, and minerals (Williams, 2007). Due to variation among animal species and post-harvesting production methods, animal protein sources often are highly variable in composition. Additionally, these products vary in quality, partly due to the body parts that these ingredients may contain.

Contribution of Animal Protein Sources to Dietary Protein Needs

Given their high protein concentration, meat tissues in raw meat and whole prey sources help meet the high protein requirement of domestic cats [adult cats: 160 g CP/kg DM for diets containing 4000 kcal metabolizable energy (ME)/kg; NRC, 2006]. Low-quality or incomplete proteins also can lead to imbalances. Two factors dictate protein quality: amino acid profile and digestibility. Providing inadequate amounts of essential amino acids or N can result in decreased protein synthesis, affecting every body system (Steiff and Bauer, 2001).

An ideal protein has the perfect ratio of individual essential amino acids and N required for optimal animal health as compared to an animal's amino acid requirements (Boisen et al., 2000; Stipanuk, 2006). Meat tissues are considered to be "complete proteins", meaning they provide the ten indispensable amino acids required by cats. Amino acid profiles have been reported for commercially available raw horse- and beef-based diets (Vester et al., 2010a) and whole prey rabbit, pigeon, pheasant, hare, sheep, and crow (Barton and Houston, 1980). All of these animal protein sources met or exceeded the essential amino acid profiles of the domestic cat (NRC, 2006).

Apparent total tract protein digestibility of raw meat sources can be high (90 to 96% CP digestibility) in domestic and captive exotic species (Vester et al., 2008; 2010a; 2010b; Kerr, 2010). When fed a commercially available raw beef-based diet, body weight was maintained and N metabolism was positive for domestic (0.68 g N/d; Kerr, 2010) and African wildcats (0.8 g N/d; Vester, 2010b). Reported values for whole prey CP digestibility (Davidson, 1978; Fekete et al., 2001; Bennett et al., 2010) may be more variable (78 to 94% CP digestibility) because of variable amounts of connective tissues and fur; however, further research is necessary to determine if those values were truly representative of felid species.

Contribution of Animal Protein Sources to Dietary Fat Needs

Cats, like all mammals, require linoleic acid (ω-6; LA) in their diet. No recommendation has been made for α-linolenic acid (ω-3; LL) in adult cats, but 0.02% is recommended for growing kittens (NRC, 2006). Linoleic acid and LL can be converted to the long-chain polyunsaturated fatty acids (PUFA) by elongation and desaturation in most mammalian species. Linoleic acid is converted to arachidonic acid (ω-6; ARA) and LL is converted to eicosapentaenoic acid (ω-3; EPA) and docosahexaenoic acid (ω-3; DHA). Pawlosky et al. (1994) reported that domestic cats have a low activity of Δ 6 desaturase, the first enzymatic step in the conversion of LA and LL to long-chain PUFA. In addition to the domestic cat, the lion (*Panthera leo*) and cheetah (*Acinonyx jubatus*) also have low Δ 6 desaturase activity (Davidson et al., 1986; Bauer, 1997). Due to this low enzymatic activity, cats may have a conditional requirement for dietary ARA, EPA, and DHA (Morris, 2003). In fact, the latest NRC (2006) recommended the inclusion of 0.01% EPA + DHA in growing and adult cats. No studies have been performed to determine the absolute requirements of long-chain PUFA in the cat.

Raw meat and whole prey sources have not been adequately studied as fat sources for felids. Whole body fat composition and fatty acid profiles can be affected by many factors, including tissue type (muscle vs. adipose), fat depot, animal species, diet, breed, sex, age, and environment. For large prey animals (i.e., raw meat sources), literature has focused on human consumption (i.e., muscle meat only) and pet food ingredients (meals and oils), as well as determining differences between tissues (i.e., subcutaneous fat vs. intramuscular fat). Data that have compared whole body fat composition among species, or examined the composition of trimmings, are lacking. Whole body composition (% fat) measurements are more common in small whole prey species (Golley, 1960; Schulte-Hostedde et al., 2001; Boos et al., 2005);

however, for these smaller species, examination of fatty acid profiles for commercially available sources is lacking.

Examination of fatty acid profiles as regards relative and total amounts of saturated (SFA), PUFA, and essential fatty acids (EFA) for large prey animals have been reported. Fatty acids in the fat depots (e.g., subcutaneous fat) are primarily in the form of triglycerides. In land mammals, these depots are mainly composed of palmitic and oleic acids, while containing low amounts of C_{20} and C_{22} PUFA (Carroll, 1965). Muscle tissues are higher in phospholipids which, in general, have more PUFA than adipose depots. In ruminants, dietary fats are hydrogenated by ruminal bacteria, resulting in more SFA and MUFA deposited in tissues as compared to the dietary fat source.

Within ruminants, differences also exist among species. Bison and other wild ruminants have been reported to have higher concentrations of PUFA when compared to domesticated beef (Cordain et al., 2002; Turner, 2005). Although this can be related to diet, species-specific differences also exist. For example, Turner (2005) reported that when bison and beef were fed the same diet, bison had higher ($P < 0.05$) LL [75 vs. 48 mg LL/g fatty acid methyl ester (FAME)], EPA (2.05 vs. 0.79 mg EPA/g FAME), DHA (5.2 vs. 3.1 mg DHA/g FAME), PUFA (124 vs. 75 mg PUFA/g FAME), and ω-3 concentrations (13 vs. 7 mg ω-3/g FAME) in intramuscular tissues compared to beef. Concentrations of these fatty acids are higher in intramuscular tissues than in subcutaneous tissues for each species, and differences were not reported among species within subcutaneous depot.

Some wild prey, such as the bank vole (*Clethrionomys glareolus*), have been reported to contain up to 25% fat on a DM basis; however, others such as the snowshoe hare (*Lepus americanus*) are very lean [2.9% fat (Powers et al., 1989)]. If whole prey animals are fed a high-

energy diet, fat concentrations may be even higher in these sources (e.g., guinea pig, 46% fat). Commercially available raw meat-based diets for captive exotic felids also have large ranges in fat content [8 to 38% of DM (Barbiers et al., 1982; Hackenburger and Atkinson, 1983; Wynne, 1989; Crissey et al., 1997; Edwards et al., 2001, 2007; Bechert et al., 2002)].

Fat is highly digestible by the cat. Apparent total tract fat digestibility values have been reported for canned and extruded diets [85 to 95% (NRC, 2006, Kerr, 2010; Vester et al., 2010b)] and raw meat diets for domestic and captive exotic felids [93 to 99% (Morris et al., 1977; Kerr, 2010; Vester et al., 2008; 2010a; 2010b; Barbiers et al., 1992)]. Fat digestibility values reported for whole prey are similar, widely variable [81 to 99% (Fekete et al., 2001; Bennett et al., 2010)]. The concentration and type of fat in a diet is important and may impact digestibility. Kane et al. (1981a) reported increased apparent total tract fat digestibility by cats fed diets containing 25 and 50% DM as fat (97 to 99%) as compared to those fed diets containing 10% DM as fat (90% digestible). Similar to this, Davidson et al. (1978) reported that apparent total tract fat digestibility was lower ($P < 0.05$) for snowshoe hare (3.7% fat) compared to other whole prey species containing a higher fat content (9 to 40% fat) when fed to fishers (81% vs. 92 to 99%).

Contribution of Animal Protein Sources to Dietary Vitamin and Mineral Needs

Proper supply of vitamins and minerals is very important for animal health and well-being. Although whole prey items should meet the requirements of felids, diet of the prey, processing (i.e., freezing, storage, etc.), and inherent characteristics of the prey species, can impact vitamin and mineral concentrations. Clum et al. (1997) analyzed commercially available domestic whole prey (mice, rats, guinea pigs, chicken, and quail), reporting deficiencies for Cu,

Fe, Mn, and vitamin E when comparing the nutrient composition to the requirements of mammalian carnivores.

Raw meat sources used in homemade diets are rarely balanced for minerals and vitamins, and usually require supplementation. Errors in supplementation may also lead to nutrient excesses or deficiencies. Streiff et al. (2002) chemically analyzed the composition of 35 homemade diets for domestic dogs and compared the data to the AAFCO recommendations at that time. Energy, fat, and protein concentrations met AAFCO recommendations in those diets, while Ca, Ca:P ratio, and vitamins A and E concentrations were lower than AAFCO recommendations.

Under-supplementation of Ca can result in loss of bone mineral content and bone pain (Krook et al., 1963), while over-supplementation results in an increased requirement for Mg, depressed food intake, and decreased growth (Howard et al., 1998). Knowledge of vitamin and mineral concentrations in whole prey and raw meat sources is indispensable for proper supplementation.

Contribution of Animal Protein Sources to Water Needs

Water needs can be met by drinking, consumption as a component of food, or from metabolic production. When fed an all meat diet or canned diet, some research has suggested that cats do not need to drink additional water to survive (Caldwell, 1931; Kane et al., 1981b; Prentiss et al., 1959). Prentiss et al. (1959) reported that when cats were maintained on beef meat or salmon (67 to 71% moisture), water balance was maintained; however, when these sources were partially desiccated (59 to 64% moisture), cats were unable to maintain balance. Similar results have been reported for cats fed canned diets [77% moisture (Kane et al., 1981b)].

While not all whole prey and raw meat diets are greater than 67% moisture, the high total water intake associated with high moisture diets may increase urine volume and decrease risk of urinary tract diseases in domestic cats due to lower saturation of urine as compared to cats fed dry diets (NRC, 2006). Therefore, in healthy cats, free access to an available source of fresh water is recommended.

Fiber, Fermentation, and Raw Meat Diets

The majority of research related to raw meat diets has focused on manipulation of protein sources, with little research on other dietary ingredients. A few experiments, however, have focused on the effects of dietary fiber source and concentration in raw meat diets. Diet*species interactions pertaining to fecal characteristics and apparent total tract macronutrient digestibility have been reported for commercially available diets (Vester et. al., 2010a), and were hypothesized to be at least partially due to differences in dietary fiber source among treatments tested (cellulose vs. beet pulp). Fiber has long been considered to provide health benefits to the colon of humans, swine, rats, etc. Because of their carnivorous origin, relatively small colon (~20% of digestive tract length), and lack of a cecum, domestic cats historically have not been studied for their ability to ferment dietary fibers. In the late 20th century, attention to dietary fiber for companion animals increased. A source of dietary fiber has become a common component in today's commercial dog and cat foods. In the cat, inclusion of dietary fiber can increase colonic weight and mucosal cell activity, including enhanced mucosal tissue energetics and short-chain fatty acid (SCFA) absorption (Bueno et al., 2000a; 2000b). These effects on colon weight and mucosal activity may be due to tactile responses from distention or abrasion of gut surface, or by chemical response to the fermentative end-products produced from the microbial breakdown of fiber.

Apparent total tract dietary fiber digestibility can range from 6 to 51% in cats (Sunvold et al., 1995b). Dietary fiber also may play a role in the digestibility of other dietary constituents. Specifically, highly fermentable, viscous fibers may interfere with the absorption of other nutrients. Sunvold et al. (1995b) reported lower ($P<0.05$) apparent total tract DM (61.3%) and N (59.0%) digestibility by cats fed a diet containing a rapidly fermentable fiber blend (35% citrus pectin, 30% locust bean gum, 20% carob bean gum, and 15% guar gum) as compared to cats fed a non-fiber treatment (DM: 88.0%; N: 86.7%).

Microbial populations of the cat are capable of degrading highly fermentable fibers (e.g., citrus pectin, guar gum, locus bean gum), but less capable of fermenting others (e.g., microcrystalline cellulose). Dietary fiber type and concentration can affect microbial populations (Terada et al., 1993; Sunvold et al., 1995a; Bueno et al., 2000b). Additionally, meat tissues may have additional materials (i.e., "animal fibers") not normally considered as fiber that analyze as TDF (Institute of Medicine, 2001). Some protein-bound polysaccharides found naturally in animal meat protein products are not susceptible to cleavage by endogenous digestive enzymes, but also may act as "fiber" and are available for fermentation (Banta et al., 1979).

The most common fiber sources added to raw meat-based diets for captive exotic felids are beet pulp and microcrystalline cellulose. Commercially available raw meat diets for domestic cats often contain a larger diversity of fiber types and dietary ingredients containing materials (e.g., oligosaccharides, vegetable material, chicory root); however, many of these sources may be unavailable to pet owners for use in homemade diets.

Beet pulp may be highly variable in its composition but, in general, it is a moderately fermentable fiber that is primarily insoluble and non-viscous. It is often high in pectin, cellulose,

and hemicelluloses. Microcrystalline cellulose is a relatively non-fermentable, insoluble, non-viscous fiber. There are also amorphous forms of cellulose that may be more fermentable. Dietary fiber often is not added to whole prey diets in zoos or by home feeders; however, ground whole prey diets have been utilized as basal diets for examining the effects of fiber (Fekete et al., 2001; 2004).

Sunvold et al. (1995b) compared fermentability of cellulose and beet pulp in cats utilizing a 24-h *in vitro* organic matter disappearance (OMD) assay and *in vivo* TDF digestibility (diets contained 11% TDF). Fermentability of beet pulp, as assessed by *in vitro* OMD, was estimated to be 35%, while *in vivo* data from cats fed diets containing beet pulp as the primary fiber source had 38% apparent total tract TDF digestibility. In comparison, cellulose had 1.2% *in vitro* OMD and 8.9% TDF *in vivo* digestibility. In another *in vitro* assay utilizing inoculum from domestic cats, Sunvold et al. (1995a) reported higher ($P < 0.05$) SCFA production per g of beet pulp than per g of cellulose (5.66 mmol SCFA/g beet pulp vs. 0.38 mmol SCFA/g cellulose). Additionally, cats fed beet pulp (Sunvold et al., 1995b) had increased ($P < 0.05$) fecal output (as-is, g/d) and decreased CP digestibility (88% vs. 83%) compared to those fed cellulose. Sunvold et al. (1995b) reported no difference in apparent total tract DM digestibility by cats fed cellulose and beet pulp (11% TDF); however, Middelbos et al. (2007) reported a decrease in apparent total tract DM digestibility by dogs fed cellulose as compared to those fed beet pulp (2.5% inclusion). Increasing the concentration of cellulose in the diet (0 to 20%) decreased apparent total tract DM and OM digestibility, but had no effect on CP or GE digestibility in cats (Leibetseder, 1984), while altering the concentration of beet pulp in dog diets (0 to 12.5% inclusion) appeared to have little influence on apparent total tract digestibility measures (Fahey et al., 1990).

Few studies have been performed to examine the effects of fiber on digestibility and fermentative criteria in captive exotic felids. Edwards et al. (2001) reported that apparent total tract DM digestibility, fecal scores, and transit time all were similar for captive exotic felids (Turmenistan caracal and Amur leopard cat) fed raw meat diets containing either beet pulp (12.6% TDF) or wood cellulose (17.1% TDF). When fed the same diet type, captive exotic felids had higher ($P < 0.05$) fecal concentrations of acetate, propionate, butyrate, and total SCFA when compared to domestic cats (Vester et al., 2010a). However, fecal SCFA concentrations are difficult to interpret because they may be due to differences in production, absorption, and/or transit time.

Conclusions

The examination of raw meat-based and whole prey diets has not been done in sufficient depth or breadth. For captive exotic felids, these are the predominant diet types fed. For domestic cats, there has been an increased popularity in feeding alternative diet types, including raw and whole prey diets, in recent years. It is important to have an understanding of the nutrient composition, digestibility, and bioavailability of these diets in felids; however, there is a paucity of peer-reviewed literature examining raw meat and whole prey diets. In addition, a majority of research pertaining to raw diets has focused on raw beef- and horsemeat-based diets, with little research performed on alternative protein sources (e.g., other species, whole prey diets) or other dietary ingredients (e.g., fiber sources and concentrations). Undoubtedly, investigations into these areas will uncover differences in composition and digestibility. The dietary composition and bioavailability of diet types has important implications as it pertains to meeting the needs of felids, including protein quality, and provision of adequate concentrations of essential fatty acids, minerals, and vitamins. The examination of commercially available alternatives, including raw

meat sources, whole prey items, and fiber sources will provide important data regarding their interactions and effects on dietary composition, digestibility, and bioavailability.

CHAPTER 3: EVALUATION OF FOUR RAW MEAT DIETS USING AVIANS, DOMESTIC CATS, AND CAPTIVE EXOTIC FELIDS

ABSTRACT

Our objective was to evaluate raw-meat diets for captive exotic and domestic carnivores containing traditional and alternative raw meat sources, specifically, beef trimmings (BE), bison trimmings (BI), elk muscle meat (E), and horse trimmings (H). We aimed to examine: diet composition and protein quality; standardized AA digestibility utilizing the cecectomized rooster assay; apparent total tract energy and macronutrient digestibility in domestic cats (DOM), African wildcats (AWC), jaguars (JAG), and Malayan tigers (MT); and metabolizable energy, N balance, and fecal fermentative end-products in DOM.

Due to variation in the meat sources, dietary proximate, AA, and long-chain fatty acid composition were variable. Our analyses indicated that all diets were lower than recommendations for essential fatty acids, and the E diet (i.e., trimmed muscle meat) was deficient in total fat. Standardized AA digestibilities measured utilizing the cecectomized rooster assay were high (> 87%). Utilizing the National Research Council minimum requirements for the growth of kittens, the first limiting AA in all diets was the combined requirement of methionine + cysteine (AA score: 81 to 95; protein digestibility corrected AA score: 75 to 90). All diets were highly digestible (88 to 89% OM digestibility). Despite differences in protein concentrations and N intake, all raw meats tested maintained N metabolism in domestic cats. There was no effect ($P > 0.05$) of diet or felid species on apparent total tract dry matter (85 to 87%), organic matter (86 to 91%), or gross energy (90 to 91%) digestibilities. Apparent crude protein digestibility was greater ($P \leq 0.05$) by cats fed E (97%) as compared to those fed BI (96%), and greater ($P \leq 0.05$) in AWC (97%) and DOM (97%) compared to MT

(95%). The diet*species interaction was significant ($P \leq 0.05$) for apparent total tract fat digestibility. In DOM, the fresh fecal pH and proportions of acetate and butyrate were altered ($P \leq 0.05$) due to diet. Diet also affected ($P \leq 0.05$) fresh fecal concentrations of total branched-chain fatty acids, valerate, and the *Lactobacillus* genus.

In conclusion, the raw meat diets were highly digestible; however, due to variation in raw meat sources, the nutrient composition of the diets varied. Thus, compositional analysis of raw-meat sources is necessary for proper diet formulation. The types of meat commonly used in raw-meat diets may be deficient in total fat (trimmed muscle meat) and essential fatty acids (trimmings and muscle meats). Additionally, differences in raw meat source nutrient composition and digestibility affect the beneficial and putrefactive fermentative end-products in feces.

INTRODUCTION

Although several studies have evaluated raw meat diets in captive exotic felids (Clauss et al., 2010; Vester et al., 2010a; 2010b), most have focused on horsemeat and beef-based diets. This is not that surprising because captive exotic felids in the US are traditionally fed horsemeat-based raw diets. With the closing of horse abattoirs in 2007, however, the availability of quality grade horsemeat in the US has decreased, increasing the need for research on the digestibility and composition of possible alternatives.

Domestic cats are the primary model for nutritional and metabolic information for captive exotic species; however, the authors are aware of only one peer-reviewed article that directly compared the domestic cat to captive exotic felids (Vester et al., 2010a). Additionally, the feeding of unconventional diets, including those based on raw meat, has increased in show

animals and pets. Further evaluation of raw meat diets in the domestic cat and other models are necessary.

The objective of this study was to evaluate four raw meat-based diets, specifically beef (BE), bison (BI), elk (E), and horse (H). We aimed to examine: diet composition and protein quality; standardized AA digestibility utilizing the cecectomized rooster assay; apparent total tract energy and macronutrient digestibility in domestic cats, African wildcats, jaguars, and Malayan tigers; and metabolizable energy (ME), fecal fermentative end-products, and blood metabolites in domestic cats.

MATERIALS AND METHODS

All animal procedures were approved by the Henry Doorly Zoo and the University of Illinois Institutional Animal Care and Use Committees prior to animal experimentation.

Diet Composition

Four raw meat-based dietary treatments were studied (Table 3.2). Based on estimated composition, all diets were formulated to meet or exceed the nutrient requirements of domestic cats (NRC, 2006). Ingredient composition of all diets was similar to diets currently fed at the Henry Doorly Zoo and included a raw meat source (BE: beef trimmings; BI: bison trimmings; E: muscle meat; H: horse trimmings), feline vitamin and mineral premix (1.3%; Meat Complete, Central Nebraska Packing, Inc., North Platte, NE) and cellulose (1.9%; Solka Floc, International Fiber, North Towanda, NY). Each dietary treatment was sub-sampled, composited, and lyophilized (Dura-Dry MP microprocessor-controlled freeze-dryer, FTS Systems, Stone Ridge, NY), then ground with dry ice through a 2-mm screen (Wiley mill model 4, Thomas Scientific, Swedesboro, NJ). Treatments were evaluated for dry matter (DM), organic matter (OM), crude protein (CP) and N (AOAC, 2006), acid hydrolyzed fat (Budde, 1952; AACC, 1983), total

dietary fiber [TDF (Prosky, 1994)], amino acids [AA; University of Missouri Experiment Station Chemical Laboratories, Columbia (AOAC, 2006)], and long-chain fatty acid (Lepage and Roy, 1986) concentrations and gross energy (GE) by bomb calorimeter (Model 1261, Parr Instrument Co., Moline, IL).

Cecectomized Rooster Assay

A cecectomized rooster assay was performed to evaluate standardized AA digestibility of the four ground, lyophilized dietary treatments. Briefly, 16 cecectomized roosters that had been fasted for 26 h to empty the digestive tract of all dietary residues were crop-intubated with approximately 20 to 30 g of one of the four dietary treatments (n = 4 roosters/diet). All excreta were collected over a 48-h period, then lyophilized and analyzed for AA according to the methods described for diet composition. Endogenous excretion of AA was measured using roosters that were fasted for 48 h. The latter values were used to calculate standardized AA digestibility values, using the method described by Sibbald (1979). Data were analyzed using the Mixed Models procedure of SAS (SAS Inst., Cary, NC). The fixed effect of diet was tested. Differences among diets were determined using a Fisher-protected LSD with a Tukey adjustment to control for experiment-wise error. A probability of $P \leq 0.05$ was accepted as statistically significant. Reported pooled standard error of the mean (SEM) were determined according to the Mixed Models procedure of SAS. Standardized digestibility was used to determine the protein digestibility corrected amino acid score (PDCAAS) utilizing the equation: PDCAAS = [[mg of AA in 1 g of test protein x standardized AA digestibility (%)]/ mg of AA in 1 g of reference protein x 100] (WHO, 2007). To determine the impact of digestibility on scores, the amino acid score (AAS) also was calculated. We utilized the equation: AAS = (mg of limiting AA in 1 g of test protein / mg of limiting AA in 1 g of reference protein) x 100. The reference pattern used

was the minimal requirements for growth of kittens provided by NRC (2006) for domestic cats. Scores were determined by selecting the amino acid with the lowest value [i.e., the first limiting AA (LAA)].

Total Tract Energy and Macronutrient Digestibility

Eight intact adult female domestic cats (DOM; *Felis catus;* mean age = 2.01 $\pm$ 0.03 yr; mean BW = 3.25 $\pm$ 0.31 kg) were fed to maintain BW and four animals of each captive exotic species [African wildcat (AWC; *Felis silvestris tristrami*), jaguar (JAG; *Panthera onca*) and Malayan tiger (MT; *Panthera tigris corbetti*)] were fed to maintain body condition. Captive exotic animal data are presented in Table 3.1. Domestic cats were housed individually in stainless steel cages (0.61 m x 0.61 m x 0.61 m) at the University of Illinois in a temperature-(21^{o}C) and light-controlled (14 h light:10 h dark) room. Exotic felids were housed individually in concrete floor enclosures maintained by the Henry Doorly Zoo in Omaha, NE. Exotic felids were allowed access to outdoor enclosures during the study (May to August). Water was provided ad libitum.

A crossover design was used with animals being randomized individually to one of the four dietary treatments. Animals were adapted to dietary treatments for 16 d prior to a 5 d collection period. During the collection period, food intake and fecal output were measured daily for all species. Fecal samples were scored daily. Scoring was conducted using a 5 point scale as follows: 1 = hard, dry pellets; 2 = dry, well-formed stools; 3 = soft, moist, formed stool; 4 = soft, unformed stool; and 5 = watery, liquid that can be poured. For each cat, total fecal output was collected for each period, composited, dried at 55^{o}C, and ground through a 2-mm screen (Wiley Mill intermediate, Thomas Scientific, Swedesboro, NJ**)**. Composited fecal samples were analyzed for DM, OM, CP, GE, and fat concentrations as described for diet

composition determination. Apparent total tract digestibility values were calculated using the following equation: [nutrient intake (g/d) - fecal output (g/d)] / nutrient intake (g/d) x 100.

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

Metabolizable Energy, Nitrogen Balance, Fresh Fecal Characteristics, and Blood Metabolites

During the collection period for DOM, total urine, fresh fecal, and serum samples were also collected. To ensure complete collection and prevent urine N loss, urine was collected and stored according to Kerr et al. (2011). Total urine samples were analyzed for GE and N concentrations as described for diet composition. Metabolizable energy was calculated using the equation: ME_C = GE intake (kcal/d) – fecal GE (kcal/d) – urinary GE (kcal/d) / DM intake (g/d). To allow for comparison of methods, dietary ME also was estimated using dietary composition and the equation: ME_E = 9 kcal/g fat + 4 kcal/g CP + 4 kcal/g nitrogen free extract (NRC, 2006). Nitrogen balance calculations were completed using the following equations: Total N output = fecal N output + urinary N output; absorbed N = N intake – fecal N output; retained N = N intake – total N output.

Fresh fecal samples were obtained within 15 min of defecation. Immediately upon collection, fresh fecal weight, pH (Denver Instrument APIO pH meter, Denver Instrument, Bohemia, NY; Beckman electrode, Beckman Instruments, Inc., Fullerton, CA) and fecal scores were determined. Fresh fecal samples were analyzed for ammonia (Chaney and Marbach,

1962), short-chain fatty acid (SCFA; acetate, butyrate, propionate) and branched-chain fatty acid [BCFA; valerate, isovalerate, isobutyrate (Erwin et al., 1961)], and phenol and indole (Flickinger et al., 2003) concentrations. Fresh fecal *Escherichia coli*, *Bifidobacterium* genus, *Lactobacillus* genus, and *Clostridium perfringens* were quantified via qPCR using specific primers according to Lubbs et al. (2009) and Middelbos et al. (2007).

Serum samples were collected on the final day of each period. Four milliliters of blood were collected from food-restricted (> 12 h) domestic cats by femoral or jugular venipuncture. Serum metabolite concentrations were determined using a Hitachi 911 clinical chemistry analyzer (Roche Diagnostics, Indianapolis, IN, USA) by the University of Illinois Veterinary Diagnostic Laboratory.

Statistical Analyses

Digestibility, N metabolism, fecal characteristic, and urine data were analyzed using the Mixed Models procedure of SAS. The fixed effects of species and diet were tested and the interaction term investigated. Period and cat were considered random effects. Differences among species were determined using a Fisher-protected LSD with a Tukey adjustment to control for experiment-wise error. A probability of $P<0.05$ was accepted as being statistically significant.

RESULTS

Dietary Composition

Dietary DM concentrations were similar in BI and H diets (34%), and similar in BE and E diets (29%; Table 3.2). Organic matter concentrations were similar among diets (93 to 95%). Crude protein, total AA (TAA), total essential AA (TEAA), and total non-essential AA (TNEAA) concentrations were lowest in BI (52%, 50%, 23%, and 26%, respectively) and

greatest in E (77%; 74%; 39%; 35%, respectively) with other protein sources being intermediate (Table 3.3). Acid-hydrolyzed fat, total fatty acid (TFA), saturated fatty acid (SFA), branched-chain fatty acid (BCFA) and monounsaturated (MUFA) concentrations, and GE values, were lowest in E (6.5%; 62 g TFA/kg DM, 27 g SFA/kg DM; 1.5 g BCFA/kg DM; 18 g MUFA/kg DM; and 5.3 kcal GE/g DM) and highest in BI (37%; 290 g TFA/kg DM; 130 g SFA/kg DM; 7.9 g BCFA/kg DM; 127 g MUFA/kg DM; and 6.6 kcal GE/g; Table 3.4). Polyunsaturated fatty acids were lowest in H (5.8 g/kg DM) and highest in the BI (8.7 g/kg DM). Linoleic acid (LA) and α-linolenic acid (LL) were lowest in E (2.7 g LA/ kg DM; 0.11 g LL/kg DM) and highest in BI (5.7 g LA/kg DM; 1.3 g LL/kg DM). Arachidonic acid (ARA) was lowest in H (0.12 g ARA/kg DM) and highest in BI and E (0.81 g ARA/kg DM). Eicosapentaenoic acid (EPA) was lowest in H (none detected) and highest in BI (0.16 g EPA/kg DM). Docosahexaenoic acid (DHA) was lowest in H (none detected) and highest in the E (2.19 g DHA/kg DM). Omega-3 PUFA were lowest in E (0.2 g/kg DM) and highest in the BE (4.6 g/kg DM), while omega-6 PUFA were lowest in BE (4.8 g/kg DM) and highest in BI (7.4 g/kg DM). The ratio of omega-6 to omega-3 PUFA was lowest in BI (4.6) and highest in E (24.5). All diets had a similar proportion of SFA (42-45% of TFA). The E diet had a higher proportion of PUFA (10 vs. 3% of TFA) compared to all other diets and lower proportion of MUFA (30 vs. 44% of TFA) compared to BE and BI, while H was intermediate (36% of TFA).

Rooster Assay

Standardized AA digestibility coefficients are presented in Table 3.5. There were few differences due to diet for individual AA. Average digestibility of all individual AA except histidine (87 $\pm$ 4%) and cysteine (88 $\pm$ 4%) were greater than 90%. Digestibility of TEAA (93 $\pm$ 2%), TNEAA (90 $\pm$ 3%), and TAA (91 $\pm$ 2%) were not different among treatments. When

evaluating AAS and PDCAAS, the first LAA for all diets was the combined requirement for methionine + cysteine. Amino acid score values were 4 to 7 points higher than PDCAAS values (Table 3.6).

Apparent Total Tract Macronutrient and Energy Digestibilities

Intake (kg/d) was higher ($P \leq 0.05$) for MT as compared to JAG, DOM, and AWC, and higher ($P \leq 0.05$) for JAG as compared to DOM and AWC (Table 3.7). For JAG and MT, intake (kg DM/d) was higher ($P \leq 0.05$) for cats fed BI and H as compared to those fed E and BE. There was no significant effect of diet for DOM or AWC. Fecal output (g DM/d) was higher ($P \leq 0.05$) for MT as compared to JAG, DOM, and AWC, and higher ($P \leq 0.05$) for JAG as compared to DOM and AWC. For JAG and MT, fecal output (g DM/d) was higher ($P \leq 0.05$) by cats fed BI as compared to those fed BE, E, and H. There was no significant effect of diet for DOM and AWC. Fecal DM was higher ($P \leq 0.05$) for DOM (59%) and AWC (55%) as compared to JAG (43%) and MT (38%), and higher ($P \leq 0.05$) for JAG as compared to MT. For DOM, fecal score was higher ($P \leq 0.05$) for cats fed BE as compared to those fed H. For BI, fecal score was higher ($P \leq 0.05$) for MT as compared to DOM. For the E diet, fecal score was higher ($P \leq 0.05$) for MT as compared to AWC and DOM. For the H diet, fecal score was higher ($P \leq 0.05$) for AWC, JAG, and MT as compared to DOM.

There was no effect of diet or species on apparent total tract DM, OM, or GE digestibilities. Apparent total tract CP digestibility was higher ($P \leq 0.05$) by AWC and DOM as compared to MT. Apparent total tract CP digestibility was higher ($P \leq 0.05$) for cats fed E as compared to those fed BI and H, and higher ($P \leq 0.05$) for those fed BE as compared to those fed BI. For cats fed BI, apparent total tract fat digestibility was higher ($P \leq 0.05$) for DOM as compared to JAG and MT, and higher ($P \leq 0.05$) for AWC as compared to JAG. There was no

significant effect of species for any other diet type. For DOM, apparent total tract fat digestibility was higher ($P \leq 0.05$) for cats fed BE, BI, and H as compared to those fed E. For JAG, apparent total tract fat digestibility was higher ($P \leq 0.05$) by cats fed H as compared to those fed BI and E.

Metabolizable Energy

Metabolizable energy values (ME_C and ME_E) were lowest for E (4.0 and 3.6 kcal ME/g DM, respectively) and highest for BI [5.7 and 5.4 kcal ME/g DM (Table 3.2)]. For BE, ME_C and ME_E were similar (0.1 kcal/d DM difference). For BI, E, and H, however, the ME_E was 0.3 to 0.4 kcal / g DM lower than the ME_C.

Nitrogen Metabolism

For cats fed E (i.e., the highest N content), fecal N (g/d) was higher ($P \leq 0.05$) compared to cats fed H and BE (Table 3.8). Urine volume (mL/d) was highest ($P \leq 0.05$) for cats fed E, and higher ($P<0.05$) for cats fed BE compared to those fed BI and H. The ratio of urine N to fecal N was not affected by diet. For cats fed E, urinary N (g/d) and total N excretion (g/d) were higher ($P \leq 0.05$) compared to cats fed BI and H. Urinary N (g/d) and total N excretion (g/d) also were higher ($P \leq 0.05$) in cats fed BE compared to those fed H. Additionally, fecal and urinary N as percentages of N intake did not differ due to dietary treatment. Absorbed N was highest ($P \leq 0.05$) for cats fed E, and higher ($P \leq 0.05$) in cats fed BE compared to cats fed BI and H. Retained N was not affected by diet.

Fecal Characteristics

Fecal concentrations of total BCFA (isobutyrate + valerate + isovalerate) were higher ($P \leq 0.05$) for cats fed E and BE as compared to those fed BI (Table 3.9). Fecal valerate concentrations were higher ($P \leq 0.05$) for cats fed BE as compared to those fed BI. The

proportion of fecal acetate was greater ($P \leq 0.05$) for cats fed BI (72.06%) as compared to cats fed E (67.22%; data not shown. The proportion of fecal butyrate was higher ($P \leq 0.05$) for cats fed E (15.64%) as compared to those fed BI (13.03%) and BE (12.64%; data not shown. The proportion of propionate was not affected by dietary treatment (15 to 17%; data not shown). Fecal pH was higher ($P \leq 0.05$) for cats fed E as compared to those fed BI. The fecal concentration of *Lactobacillus* genus was higher ($P \leq 0.05$) for cats fed BI as compared to those fed E. Fecal concentrations of ammonia, total SCFA (acetate + butyrate + propionate), acetate, butyrate, propionate, isobutyrate, isovalerate, phenol, indole, *Bifidobacterium* genus, *C. perfringens*, and *E. coli* were not affected by diet.

Blood Metabolites

Blood metabolite coefficients and reference ranges (Merck, 2005; Kluger et al., 2009) are presented in Table 3.10. Blood sodium was higher ($P \leq 0.05$) than reference values for cats fed H (156.3 mmol Na/L). Blood alanine amino transferase (ALT) was higher ($P \leq 0.05$) than reference values in cats fed BE, E, and H (68.1, 67.3, and 62.0 U ALT/L). Although some values were numerically above the reference range values, the remaining blood metabolites did not differ ($P > 0.05$) from reference ranges, and there were few differences due to dietary treatment.

DISCUSSION

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

Meat trimmings are readily available protein and fat sources that are commonly included in commercial and zoo diets for captive exotic felids, and are available for use in homemade raw meat diets for domestic carnivores. Trimmings are composed of excess tissue after slaughter; however, they are highly variable and can be high in fat. The use of muscle meat is more common in homemade diets, but the high volume required for exotic animals would be cost-preventive. The protein source for the BE, BI, and H diets was trimmings. The protein source for the E diet was composed of muscle meat. Despite the simple ingredient composition of the diets, variation in the protein sources resulted in highly variable nutrient composition. Thus, differences due to diet cannot be attributed to protein source or macronutrient composition alone.

Macronutrient Composition.

All diets fed herein contained similar DM (25 to 43%), OM (84 to 96%), and CP (41 to 84%) concentrations to raw-meat based diets fed to captive exotic felids in previous studies (Vester et al., 2010a; 2010b; Kerr et al., 2011). The BE, BI, and H diets had similar fat concentrations [9 to 37% of DM (Vester et al., 2010a; 2010b; Kerr et al., 2011)]. The muscle meat of the E diet, however, was over-trimmed, and the resulting fat concentration (6.5%) was lower than our estimates and the requirements for domestic cats (90 g/kg DM for diets with 4000 kcal ME/kg DM; NRC, 2006). These data indicate that when muscle meats are used as the primary protein source, an additional fat may be necessary. Macronutrient composition of all diets was within the ranges reported for pet ingredients of animal origin (NRC, 2006).

Long-Chain Fatty Acid Composition.

Examinations of fatty acid profiles with specific reference to relative and total amounts of SFA, PUFA, and essential fatty acids (EFA) in large animals (i.e., raw meat sources) have been reported; however, fatty acid profiles can be affected by many factors, including tissue (muscle

vs. adipose), fat depot, animal species, diet, breed, sex, age, and environment. Literature has focused on muscle meat quality and tissue depot differences. Because trimmings are composed of a mixture of intra- and inter-muscular fat tissues, and dietary information on the animals is unknown, it is likely that generalizations regarding trends in fat composition will not be true when examining trimmings. Although species-specific differences have been noted in intramuscular fat composition between beef and bison species, the BE and BI diets (i.e., ruminant species) had the most similar pattern of fat composition in this study. This was likely due to the high amount of intermuscular fat, which has been noted to be similar between these species (Turner, 2005). All diets contained similar proportions of total fatty acids as SFA (42-45%). Ruminants deposit greater amounts of SFA and MUFA in their tissues than contained in their diets, so it is not surprising that the BE and BI diets had numerically higher MUFA concentrations than E and H diets (44% vs. 30 and 36%, respectively). Because the E diet was mainly composed of muscle tissue, the higher proportion of PUFA (10%) as compared to BE, BI, and H (3%) may have been due to the increased amount of phospholipids in intramuscular fat as compared to intermuscular fat.

Cats, like all mammals, require LA (ω-6) in their diet. Due to low activity of Δ 6 desaturase (Davidson et al., 1986; Pawlosky et al., 1994; Bauer, 1997), cats may have a conditional requirement for dietary ARA (ω-6), EPA (ω-3), and DHA [ω-3 (Morris, 2003; NRC, 2006)]. Additionally, LL (ω-3) recommendations are provided for kittens after weaning and during gestation and lactation (NRC, 2006). No studies have been performed to determine the absolute requirements of long chain polyunsaturated fatty acids in the cat. All diets fed herein were adequate sources of LL (0.2 g/kg DM for diets with 4000 kcal ME/kg DM; NRC, 2006); however, for all life stages, none met the recommended levels of LA (5.5 g/kg DM for diets with

4000 kcal ME/kg DM; NRC, 2006). The E and H diets were also lower than the combined recommendation for EPA and DHA (0.1 g/kg DM for diets with 4000 kcal ME/kg DM; NRC, 2006). The H diet had a lower ARA than that recommended for kittens, gestation, and lactation (0.2 g/kg DM for diets with 4000 kcal ME/kg DM; NRC, 2006).

Amino Acid Composition and the Rooster Assay

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

Determining the bioavailability of individual amino acids allows for improved feed formulation. The precision-fed cecectomized rooster assay is used extensively for determining AA digestibility of feed ingredients. Cecectomy allows for digestibility estimates to be made without the confounding effect of microbial fermentation and protein from the ceca of the birds,

and requires less time and monetary commitment than ileal cannulation assays. It has been used to examine both animal and plant protein sources for use in pet foods (Folador et. al., 2006; de Godoy et. al., 2009; Johnson et. al., 1998; Faber et al., 2010). Johnson et al. (1998) directly compared the cecectomized rooster assay and the ileal-cannulated dog assay, and reported that it was appropriate for predicting variation in AA digestibility among animal meals for dogs. The authors are aware of no direct comparison with the ileal-cannulated cat assay; however, for proteins with greater than 90% protein digestibility, it is generally accepted that there is no difference between cats and dogs (Kendall et al., 1982).

The cecectomized rooster results reported herein indicate that standardized AA digestibility was high for all diets. Values for individual AA, TAA, TEAA, and TNEAA were greater than those reported for meat and bone, lamb, and poultry by-product meals [62-82% TAA digestibility (Wang and Parsons, 1998; Johnson et al., 1998)], but similar to values reported for fish by-products, fish meals, and fish substrates [86-92% TAA digestibility (Folador et al., 2006; Faber et al., 2010)]. Processing technique, and presence of connective tissue can affect AA digestibility. Because the diets were fed raw, there was no decrease in digestibility due to heat exposure or other processing techniques. While there were differences in connective tissue many diets, it did not negatively affect AA digestibility.

Apparent Total Tract Macronutrient Digestibility

Intake and fecal output were influenced by both diet and species, with larger species eating and defecating more. The large volumes eaten by MT and JAG in combination with differences in dietary DM concentrations among diets resulted in DMI differences among these species. For JAG and MT, fecal output was increased in cats fed BI, likely due to decreased fat and protein digestibility, respectively.

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

Due to the higher number of domestic cats (n = 8), differences in fat digestibility for DOM may have easier to detect statistically (i.e., the E diet had decreased fat digestibility compared to the other diets), while no differences were observed in captive exotic species (n=4). Because most of the fat in the E meat source was trimmed off, there was little intermuscular fat in the diet, meaning that less available forms of fat (e.g., intramuscular fat; fatty acids from phospholipids) likely made up a higher percentage of the dietary fat. Additionally, because the dietary fat concentration was low, endogenous fat excretion and losses during fat analysis may have impacted digestibility calculations greater than those for higher fat diets. Kane et al. (1981a) reported similar results; with increased apparent total tract fat digestibility observed in domestic cats fed diets containing 25 and 50% DM as fat (97 to 99%) as compared to those fed diets with 10% DM as fat (90%). Similarly, Davidson et al. (1978) reported that a diet composed of snowshoe hare (3.7% dietary fat) had a lower fat digestibility (81%) when compared to other whole prey diets (9 to 40% dietary fat; 92 to 99% digestibility) when fed to fishers. Reported values for apparent total tract CP digestibility by domestic and captive exotic species are variable (73 to 96% CP digestibility); however, more recent trials, including the one herein, report that raw meat sources can be highly digestible [90 to 97% CP digestibility (Vester et al., 2010a;

2010b; Kerr et al., 2011)]. Even though colonic fermentation of proteins can skew total tract CP digestibility data, the CP digestibility values reported herein agree with the rooster AA digestibility data, and indicate very high digestibility of the protein. Differences among species were noted for CP digestibility; however, in regards to protein quality, these differences (< 2% units difference) are likely biologically insignificant.

In addition to high CP digestibility, the diets fed herein also yielded positive N balance in DOM. Although retained N was positive, cats maintained BW. This phenomenon is common in domestic cat N balance studies that examine high protein diets and is due to N that is unaccounted for rather than truly positive N balance. Values reported here in are similar to those in the literature for extruded (Funaba et al., 2001, 2002) and purified diets (Green et al., 2008).

In this study, it appears that the smaller species have increased digestive capacity compared to larger animals; however, further research would be necessary to determine if BW or size may impact CP digestibility. Vester et al. (2010a) reported increased digestibility in smaller species, while Vester et al. (2008) reported no differences among species. The differences observed among diets were likely due to differences in ingredient composition. Compared to the E diet, diets that contained trimmings had less available forms of protein (e.g., connective tissues containing collagen) making up a higher percentage of the dietary protein. Fermentation in the large bowel also impacts apparent total tract CP digestibility, and must be considered. When ileal CP digestibility is decreased, an increased amount of protein enters the large bowel and may be fermented by hindgut microbiota. This may lead to an increased production of bacterial protein, which will be excreted in the feces, thereby underestimating apparent total tract CP digestibility.

Metabolizable Energy

The National Research Council (NRC) recommends utilizing the Atwater values of 9, 4, and 4 kcal ME/g for fat, protein, and NFE, respectively, to estimate ME of unprocessed cat foods (NRC, 2006). Although this method (ME_E) slightly underestimated the ME calculated (ME_C) in the DOM for BI, E, and H diets, the pattern among diets was similar for both methods. Therefore, the NRC method would have been appropriate for examining the difference among diets. Underestimation by this method of calculation is likely due to the simple nature of our diets and the high digestibility values, but may be more appropriate for more complex formulations.

Fecal Characteristics

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

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

All diets fed herein utilized cellulose as a fiber source. Given the non-fermentable nature of this fiber, we expected concentrations of fermentative end-products to be low. Fecal concentrations of SCFA, BCFA, phenols, and indoles in the current study were similar to those reported for domestic cats fed raw meat-based diets containing cellulose as a fiber source (Vester et al., 2010a; Kerr et al., 2011), but lower than those fed raw meat and traditional extruded diets containing beet pulp as a fiber source (Vester et al., 2010a; 2010b; Kerr et al., 2011). Fecal concentrations of SCFA, BCFA, phenols, and indoles were lower than those reported for captive exotic felids [246 to 1689 umol SCFA/g DM feces; 19.8 to 202 umol BCFA/g DM feces (Vester et al., 2008; 2010a)]. It is also worth noting that no differences in fecal characteristics were

observed between cats fed H and BE diets in this study, which indicates that the differences reported by Vester et al. (2010a) were likely due to other dietary ingredient differences or ingredient interactions.

Because of the simple ingredient composition herein, protein source was the primary substrate available for fermentation. Differences in dietary CP concentrations likely contributed to the differences observed in fermentative end-products. We expected increased dietary protein concentration to increase protein intake, and thus potentially increase indicators of protein fermentation, including increased fecal pH and concentrations of ammonia, phenol, indole, and BCFA. Although fecal ammonia, phenol, and indole concentrations were not different, when compared to data for cats fed BI (the diet with lowest CP), cats fed E (diet with the highest CP) had higher fecal pH and total BCFA concentrations, and cats fed H (diet with second highest CP) had higher fecal total BCFA concentrations.

The alterations to the gut environment due to high protein fermentation may cause shifts in microbial populations. The decreased fecal concentrations of *Lactobacillus* genus, decreased acetate proportion, and increased butyrate proportion in cats fed E (compared to those fed BI), are likely due to such microbial shifts. The potential to alter microbial species and fecal characteristics by dietary protein source and concentration warrants further investigation.

Blood Metabolites

Diagnostically, it is important to understand how feeding raw meat diets may impact serum chemistry. However, because of the paucity of data on blood metabolites reported in domestic cats fed raw meat (Kerr et al., 2011), it is unclear how the ingredient and macronutrient composition differences between raw meat-based diets and traditional diets can impact the serum profile.

Elevated serum ALT concentrations can be diagnostically indicative of dysfunction or toxic insult of the liver (Merck, 2005). Alanine aminotransferase concentrations similar to those herein, and above the reference range provided, have been reported in domestic cats (67.8 U/L; Kerr et al., 2011), African wildcats (79 U/L; Vester et al., 2010b), and dogs (23-112 U/L; Beloshapka, 2011) fed raw meat diets. Kerr et al. (2011) also reported elevated serum albumin concentrations when cats were fed a raw meat diet (4.0 to 4.1 g/dL). Although not significantly different, serum albumin concentrations reported herein were at the upper end of the reference range in cats fed BI and H, and slightly elevated in cats fed BE and E diets. Increased serum albumin can be due to high protein intake or dehydration. Because the diets fed herein had high moisture content, it was likely that the elevated serum albumin concentrations were due to the high protein content of raw meat diets. Additionally, urea N, sodium, and cholesterol concentrations also were at the upper end of the reference ranges. These data may indicate that further research is warranted to determine if separate reference ranges may be necessary for animals fed raw diets and what the long-term health effects of these differences may be.

Conclusions

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

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

TABLES

Table 3.1 Sex, body weight, body condition score (BCS), and age of captive exotic felids

Species	Sex	BW[1] (kg)	BCS[2]	Age (y)
African wildcats	F	3.1	3.0	4.0
	F	3.3	3.0	4.0
	M	4.6	3.0	2.9
	M	3.7	3.0	2.9
Jaguars	F	50	3.0	6.9
	M	51	3.0	6.0
	M	57	3.5	1.9
	M	59	3.0	19.0
Malayan tigers	F	103	3.0	3.3
	F	88	3.0	13.4
	F	96	2.5	13.4
	M	97	3.0	8.0

[1]Determined at most recent medical examination.

[2] BCS = Body condition score; Determined on a 5-point scale with 1 = emaciated, 3 = ideal, and 5 = obese. All BCS were determined with special consideration of the species being evaluated (e.g., structural differences in body frame).

Table 3.2 Ingredient and chemical composition of beef-, bison-, elk-, and horsemeat-based raw diets fed to domestic and captive exotic felids [Dry matter (DM) basis]

Item	Beef	Bison	Elk	Horse
DM, %	29.0	34.1	28.8	34.1
Organic matter, %	93.1	95.3	93.2	94.6
Crude protein, %	64.5	52.2	76.6	59.0
Acid hydrolyzed fat, %	22.2	36.6	6.5	25.1
Total dietary fiber, %	8.4	6.6	12.0	7.2
Gross energy, kcal/g	5.9	6.6	5.3	6.0
Calculated ME[1], kcal/g	4.7	5.7	4.0	5.1
Estimated ME[2], kcal/g	4.6	5.4	3.6	4.8

Ingredient composition of all diets: raw meat source [BE: beef trimmings (Central Nebraska Packing, Inc); BI: bison trimmings (Natural Prairie Gold); E: muscle meat (Henry Doorly Zoo); H: horse trimmings (Central Nebraska Packing, Inc), feline vitamin premix (vitamin A acetate, thiamine mononitrate, d-calcium pantothenate, mineral oil, d-biotin, pyridoxine hydrochloride, vitamin D3 supplement), taurine, feline mineral premix (zinc oxide, manganous oxide, copper oxide, mineral oil, sodium selenite, calcium iodate), and Solka floc.

[1]Calculated ME = GE intake (kcal/d) – fecal GE (kcal/d) – urinary GE (kcal/d) / DMI (g/d).
[2]Estimated ME = 9 kcal/g fat + 4 kcal/g CP + 4 kcal/g nitrogen free extract (NRC, 2006).

Table 3.3 Amino acid composition of beef-, bison-, elk-, and horsemeat-based raw diets fed to domestic and captive exotic felids (% dry matter)

Item	Beef	Bison	Elk	Horse
AA, %	62.68	49.73	73.99	56.70
TEAA[1]	30.60	23.46	38.55	28.34
Arginine	4.15	3.43	4.84	3.80
Histidine	2.12	1.40	2.98	2.18
Isoleucine	2.93	2.09	3.67	2.73
Leucine	5.08	3.91	6.44	4.68
Lysine	5.45	4.06	6.95	4.89
Methionine	1.58	1.15	2.07	1.42
Phenylalanine	2.56	2.04	3.22	2.36
Taurine	0.21	0.46	0.37	0.24
Threonine	2.57	1.92	3.20	2.34
Tryptophan	0.70	0.49	0.80	0.67
Valine	3.28	2.52	4.03	3.03
TNEAA[2]	32.08	26.26	35.44	28.37
Alanine	4.08	3.33	4.52	3.60
Aspartate	5.61	4.31	6.92	5.16
Cysteine	0.65	0.49	0.77	0.57
Glutamate	9.15	6.78	10.93	8.14
Glycine	4.17	4.12	3.55	3.61
Hydroxylysine	0.14	0.12	0.06	0.07
Hydroxyproline	0.86	1.12	0.19	0.56
Lanthionine	0.00	0.00	0.00	0.00
Ornithine	0.08	0.06	0.14	0.07
Proline	2.95	2.75	2.89	2.66
Serine	2.07	1.55	2.28	1.75
Tyrosine	2.34	1.64	3.21	2.19

[1] TEAA = total essential amino acids.
[2] TNEAA = total non-essential amino acids.

Table 3.4 Long-chain fatty acid concentrations of beef-, bison-, elk-, and horsemeat-based raw diets fed to domestic and captive exotic felids (mg/g dry matter)

Item	Beef	Bison	Elk	Horse
Total fatty acids	173.64	289.63	61.90	185.91
Linoleic acid	3.24	5.73	2.71	4.39
α-linolenic acid	0.61	1.25	0.11	0.73
Arachidonic acid	0.64	0.81	0.81	0.12
Eicosopentaenoic acid	0.15	0.16	0.02	ND[1]
Docosahexaenoic acid	0.03	0.08	2.19	ND
Total SFA[2]	78.45	130.21	27.37	77.95
Total BCFA[3]	4.71	7.94	1.51	3.13
Total MUFA[4]	77.20	126.52	18.45	66.93
Total n-3 PUFA[5]	0.88	1.62	0.23	0.73
Total n-6 PUFA	4.48	7.06	5.69	5.01
Total PUFA	5.36	8.68	5.92	5.75
CLA[6]	1.59	1.63	0.13	2.61
n-6: n-3	5.06	4.62	24.45	8.32

[1] ND = none detected.
[2] SFA = saturated fatty acids.
[3] BCFA = branch chain fatty acids.
[4] MUFA = monounsaturated fatty acids.
[5] PUFA = polyunsaturated fatty acids.
[6] CLA = conjugated linoleic acid.

Table 3.5 Standardized digestibility (%) of amino acids (AA) of beef-, bison-, elk-, and horsemeat-based raw diets determined using the precision-fed cecectomized rooster assay[1]

	Diet					
AA	Beef	Bison	Elk	Horse	SEM	P - value
Essential						
Arginine	94.3	94.3	91.1	92.7	1.8	0.55
Histidine	89.8	88.6	84.3	84.7	1.4	0.06
Isoleucine	96.5	95.9	96.5	94.7	0.5	0.07
Leucine	96.9	96.5	97.0	95.5	0.5	0.13
Lysine	91.4	91.8	90.7	88.2	2.5	0.74
Methionine	97.5	96.8	97.2	96.1	0.4	0.13
Phenylalanine	95.7^{ab}	95.3^{ab}	96.0^{b}	93.5^{a}	0.6	0.04
Threonine	95.3	95.0	95.3	93.4	0.8	0.34
Tryptophan	98.3^{ab}	99.5^{bc}	97.1^{a}	98.8^{bc}	0.4	0.01
Valine	95.5	94.7	96.1	93.8	0.7	0.19
Non-essential						
Alanine	96.0	95.5	96.3	94.4	0.6	0.14
Aspartate	95.8	95.2	95.7	94.1	0.6	0.19
Cysteine	90.8	87.1	88.6	84.6	2.0	0.23
Glutamate	95.5	95.4	95.0	94.5	0.5	0.55
Proline	94.0	93.5	93.1	90.8	1.1	0.21
Serine	94.8	93.6	94.8	92.3	1.1	0.36
Tyrosine	94.5^{b}	94.3^{ab}	92.1^{ab}	91.2^{a}	0.8	0.03
TEAA[1]	94.1	93.2	92.8	91.7	0.9	0.39
TNEAA[2]	91.9	90.3	88.1	87.6	1.4	0.16
TAA[3]	93.0	91.7	90.6	89.7	1.1	0.24

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

[1] Data are means of 4 roosters.

[2] TEAA = total essential amino acids.

[3] TNEAA = total nonessential amino acids.

[4] TAA = total amino acids.

Table 3.6 Amino acid score (AAS), protein digestibility-corrected amino acid score (PDCAAS), and first limiting amino acid (LAA) of beef-, bison-, elk-, and horsemeat-based raw diets fed to domestic and captive exotic felids [1]

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

[1] Utilizing minimal requirements for growth of kittens as reference values (NRC, 2006).

Table 3.7 Food intake, fecal output, fecal characteristics, and apparent total tract macronutrient digestibility by domestic (n = 8) and captive exotic felids (n = 4 per spp.) fed beef-, bison-, elk-, and horsemeat-based raw diets

Item	Diet					P - value		
	Beef	Bison	Elk	Horse	SEM	Diet	Species	Diet* Species
Intake, g DM/d						< 0.01	< 0.01	< 0.01
African wildcat [x]	49.8	58.9	49.3	58.4	32.4			
Domestic cat [x]	45.0	49.5	49.5	38.2	22.9			
Jaguar [y]	503.0 [ab]	593.1 [c]	460.0 [a]	527.7 [bc]	32.5			
Malayan tiger [z]	937.3[a]	1069.8 [b]	927.5 [a]	1062.9 [b]	32.7			
Output, g DM/d						< 0.01	< 0.01	< 0.01
African wildcat	6.2	8.0	7.1	7.1	5.8			
Domestic cat	7.0	6.0	7.7	4.9	4.2			
Jaguar	65.2[a]	91.3[b]	64.9[a]	66.6[a]	6.1			
Malayan tiger	148.4[a]	173.9[b]	139.5[a]	152.3[a]	6.2			
Fecal DM, %						0.16	< 0.01	0.25
African wildcat [x]	56.5	54.2	57.6	51.4	2.3			
Domestic cat [x]	54.1	59.4	62.5	60.1	1.7			
Jaguar [y]	42.5	43.0	45.0	41.9	2.3			
Malayan tiger [z]	37.7	37.8	37.6	39.1	2.3			
Fecal Score[1]						0.04	< 0.01	< 0.01
African wildcat	2.2	2.4[xy]	2.1[x]	2.7[y]	0.2			
Domestic cat	2.2[a]	2.0[abx]	1.8[abx]	1.7[bx]	0.2			
Jaguar	2.8	2.7[xy]	2.8[xy]	3.1[y]	0.2			
Malayan tiger	3.0	3.1[y]	3.2[y]	3.6[y]	0.2			

Table 3.7 continued Food intake, fecal output, fecal characteristics, and apparent total tract macronutrient digestibility by domestic (n = 8) and captive exotic felids (n = 4 per spp.) fed beef-, bison-, elk-, and horsemeat-based raw diets

Item	Diet				SEM	P - value		
	Beef	Bison	Elk	Horse		Diet	Species	Diet* Species
DM Digestibility, %						0.30	0.17	0.13
African wildcat	87.2	86.5	85.8	88.1	1.4			
Domestic cat	84.1	88.1	84.3	87.1	1.1			
Jaguar	87.0	83.6	86.0	86.3	1.4			
Malayan tiger	84.2	84.7	84.6	85.7	1.5			
OM Digestibility, %						0.30	0.09	0.10
African wild cat	89.8	89.0	89.2	90.6	1.2			
Domestic cat	87.4	90.4	87.7	89.8	0.9			
Jaguar	89.8	86.0	88.7	88.9	1.2			
Malayan tiger	86.7	86.9	88.0	88.3	1.3			
CP Digestibility, %						< 0.01	< 0.01	0.31
African wild cat [y]	97.2[bc]	96.3[a]	97.5[c]	96.3[ab]	0.4			
Domestic cat [y]	96.6[bc]	96.8[a]	97.3[c]	96.8[ab]	0.3			
Jaguar [xy]	96.9[bc]	95.6[a]	97.3[c]	96.1[ab]	0.5			
Malayan tiger [x]	95.2[bc]	94.3[a]	96.3[c]	95.2[ab]	0.5			
Fat Digestibility, %								
African wild cat	95.0	95.9[yz]	90.5	95.6	1.6	< 0.01	0.03	< 0.01
Domestic cat	95.0[b]	96.8[bz]	88.8[a]	97.2[b]	1.0			
Jaguar	93.8[ab]	87.2[ax]	89.3[a]	96.3[b]	1.5			
Malayan tiger	90.5	92.1[xy]	88.3	93.8	1.5			

Table 3.7 continued Food intake, fecal output, fecal characteristics, and apparent total tract macronutrient digestibility by domestic (n = 8) and captive exotic felids (n = 4 per spp.) fed beef-, bison-, elk-, and horsemeat-based raw diets

Item	Diet					P - value		
	Beef	Bison	Elk	Horse	SEM	Diet	Species	Diet* Species
GE Digestibility, %						0.11	0.05	0.02
African wild cat	92.3	90.9	91.1	92.5	1.1			
Domestic cat	90.3	92.7	89.9	92.2	0.8			
Jaguar	92.0	87.3	90.8	91.2	1.1			
Malayan tiger	88.9	89.2	89.7	90.2	1.2			

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

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

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

Table 3.8 Nitrogen (N) metabolism in domestic cats fed beef-, bison-, elk-, and horsemeat-based raw meat diets

Item	Beef	Bison	Elk	Horse	SEM	P - Value
Intake						
Dietary moisture, mL/d	111.8[c]	88.1[b]	122.8[c]	72.1[a]	5.01	<0.001
N, g/d	4.7[b]	3.9[a]	6.2[c]	3.6[a]	0.22	<0.001
Fecal Output						
DM, g/d	7.0[bc]	6.0[ab]	7.7[c]	4.9[a]	0.52	<0.001
N, g/d	0.157[a]	0.123[ab]	0.165[b]	0.116[a]	0.0130	0.012
Urinary Output						
Volume, mL/d	78.0[b]	54.9[a]	96.5[c]	47.5[a]	4.23	<0.001
N, g/d	3.9[bc]	3.4[ab]	4.9[c]	2.7[a]	0.31	<0.001
Total N Output	4.0[bc]	3.5[ab]	5.0[c]	2.8[a]	0.32	<0.001
Absorbed N, g/d	4.6[b]	3.7[a]	6.1[c]	3.5[a]	0.23	<0.001
Retained N, g/d	0.68	0.36	1.21	0.81	0.342	0.148

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

Table 3.9 Fecal characteristics of domestic cats (n = 8) fed beef-, bison-, elk-, and horsemeat-based raw diets (DM basis)

	Diet					
Item	Beef	Bison	Elk	Horse	SEM	P-value
pH	7.16[ab]	6.89[a]	7.23[b]	7.12[ab]	0.11	0.03
Ammonia, umol/g	221.57	253.47	255.51	214.29	23.37	0.38
Phenol, umol/g	0.07	0.07	0.11	0.11	0.07	0.74
Indole, umol/g	0.28	0.46	0.54	0.49	0.08	0.08
SCFA[1], umol/g	112.65	91.14	101.69	84.03	10.37	0.16
Acetate	79.69	65.47	68.71	58.78	7.43	0.15
Butyrate	13.83	11.69	15.45	12.28	1.21	0.21
Propionate	19.12	13.98	17.54	12.97	2.16	0.09
BCFA[2], umol/g	15.60[b]	11.15[a]	15.12[b]	14.39[ab]	1.06	0.01
Isobutyrate	3.51	2.99	3.70	3.22	0.28	0.15
Isovalerate	5.14	4.45	5.93	5.35	0.45	0.13
Valerate	6.94[b]	3.71[a]	5.80[ab]	5.82[ab]	0.62	0.01
Microbes, log CFU[3]/g						
Lactobacillus genus	10.04[ab]	10.21[b]	9.79[a]	10.08[ab]	0.95	0.01
Bifidobacterium genus	6.01	6.04	5.84	6.01	0.07	0.16
Clostridium perfringens	10.41	10.51	10.57	10.40	0.13	0.67
Escherichia coli	10.01	10.34	9.98	9.96	0.16	0.29

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

[1] SCFA = acetate + butyrate + propionate.

[2] BCFA = isobutyrate + isovalerate + valerate.

[3] CFU = colony forming units.

Table 3.10 Food-restricted blood metabolite concentrations for domestic cats (n=8) fed beef-, bison-, elk-, and horsemeat-based raw diets.

	Diet						
Item	Beef	Bison	Elk	Horse	SEM	P - value	Reference Range[1]
Urea nitrogen, mg/dL	30.6[ab]	27.7[a]	31.7[b]	29.5[ab]	1.19	0.03	15.4 to 31.2
Total protein, g/dL	7.2	7.1	7.3	7.0	0.17	0.20	5.7 to 8.0
Albumin, g/dL	3.8	3.7	3.8	3.7	0.12	0.87	2.4 to 3.7
Calcium, mg/dL	10.0	9.7	9.8	10.0	0.18	0.30	7.9 to 10.9
Phosphorus, mg/dL	5.2[ab]	5.2[ab]	5.3[b]	4.9[a]	0.17	0.03	4.0 to 7.3
Sodium, mmol/L	155.3[ab]	154.6[ab]	152.5[b]	156.3[a]	1.00	0.05	140.3 to 153.9
Potassium, mmol/L	4.7[ab]	4.7[a]	5.0[b]	4.8[ab]	0.08	0.02	3.8 to 5.3
Chloride, mmol/L	118.0[ab]	117.5[ab]	116.6[b]	119.5[a]	0.84	0.05	107.5 to 129.6
Glucose, mg/dl	75.5	80.0	74.0	78.4	3.39	0.41	60.8 to 124.2
ALT[2], U/L	68.1[b]	54.9[a]	67.3[b]	62.0[ab]	4.06	0.05	8.3 to 52.5
Cholesterol, mg/dL	163.1[ab]	150.6[a]	144.9[a]	173.3[b]	6.86	< 0.01	71.3 to 161.2
Bicarbonate, mmol/L	17.7[ab]	17.8[ab]	17.2[a]	19.0[b]	0.54	0.02	16.4 to 22.0
Creatinine, mg/dL	1.6	1.6	1.6	1.8	0.07	0.10	0.5 to 1.9
NEFA, mEq/L	0.6	0.6	0.6	0.7	0.072	0.27	NA[3]
Triglycerides, mg/dL	33.9[ab]	30.0[a]	39.3[b]	34.3[ab]	2.23	0.01	8.9 to 71.2[4]

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

[1]MERCK Veterinary Manual (2005).

[2] ALT = Alanine aminotransferase.

[3] NA = None available.

[4] Kluger et al. (2009).

CHAPTER 4: INFLUENCE OF DIETARY FIBER TYPE AND AMOUNT ON NUTRIENT DIGESTIBILITY, FECAL CHARACTERISTICS, AND FECAL FERMENTATIVE END-PRODUCT CONCENTRATIONS OF CAPTIVE EXOTIC FELIDS FED A RAW BEEF-BASED DIET

ABSTRACT

Little nutritional or metabolic information has been collected from captive exotic cats fed raw diets. In particular, the optimal fiber type and concentration for use in raw meat-based diets for captive exotic felids has not been determined. Our objective was to evaluate the effects of fiber type and concentration on apparent total tract macronutrient digestibility, fecal characteristics, and fecal fermentative end-products in captive exotic felids. Four animals of each captive exotic species (jaguar, cheetah, Malayan tiger, and Siberian tiger) were randomized in a cross over design to one of the four dietary treatments: 2% cellulose (2C), 4% cellulose (4C), 2% beet pulp (2BP), and 4% beet pulp (4BP). Felid species, fiber type, and fiber concentration all impacted digestibility and fecal fermentative end-products. Inclusion of BP increased ($P \leq 0.05$) fecal short-chain fatty acids and fecal output in all cats. Inclusion of 2C, 4C, and 4BP increased ($P \leq 0.05$) fecal bulk and diluted fecal branched-chain fatty acids concentrations compared to 2BP. Apparent total tract dry matter, organic matter, fat, and gross energy digestibilities decreased ($P \leq 0.05$) linearly with BW. Additionally, fecal moisture, fecal score, and concentrations of fermentative end-products increased ($P \leq 0.05$) with BW. In conclusion, the optimum fiber type and concentration for inclusion in captive exotic felid diets is likely a combination of fermentable and non-fermentable fibers with the optimal fiber blend being dependent on species. Smaller cats, such as cheetahs and jaguars, tolerated fermentable fibers, while larger cats, such as Malayan and Siberian tigers, required more insoluble fibers that limit fermentation and provide fecal bulk.

INTRODUCTION

Little nutritional or metabolic information has been collected from captive exotic cats fed raw diets. Anecdotally in the US, horsemeat-based diets have been considered superior to beef-based diets. With the closing of horse abattoirs in 2007, the availability of quality grade horsemeat for use in US zoological institutions has decreased, creating a need to identify and test alternatives.

Vester et al. (2010a) evaluated traditional horse- and beef-based diets fed to captive exotic felids and reported increased apparent total tract DM and OM digestibilities, and fecal fermentative end-products, in cats fed beef-based compared to those fed horsemeat-based diets. Because fiber source was a major difference between the diets fed, with the beef-based diet containing beet pulp and the horsemeat-based diet containing cellulose, differences could not be attributed to meat source alone

As discussed in Chapter 3, we observed no differences in apparent total tract macronutrient digestibility or fecal fermentative end-product concentrations in captive exotic felids fed horsemeat- and beef-based raw diets of similar macronutrient profiles and composed of a meat source, a vitamin and mineral premix, and cellulose. That study indicated that the differences between diets reported by Vester et al. (2010a) may have been due to differences in dietary fiber, other ingredients, or interactions among various factors.

Understanding the role of dietary fiber in the captive exotic felid may allow for the formulation of more appropriate diets. For domestic cats, incorporation of fiber is important for providing fermentation end-products that promote gastrointestinal health, maintaining stool quality, modulating metabolism, and diluting energy dense diets (Verbrugghe et al., 2009; 2010; Sunvold et al., 1995b; Barry et al., 2010). Our objective was to evaluate the effects of fiber type

and concentration on apparent total tract macronutrient digestibility, fecal characteristics, and fecal fermentative end-product concentrations in captive exotic felids fed a raw beef-based diet.

MATERIALS AND METHODS

All animal procedures were approved by the Henry Doorly Zoo Institutional Animal Care and Use Committee prior to animal experimentation. Four animals of each captive exotic species [jaguar (JAG), cheetah (CHE), Malayan tiger (MT), and Siberian tiger (ST)] were fed to maintain body condition. Animal characteristics are presented in Table 4.1. A crossover design was used with animals being randomized individually to one of the four dietary treatments: 2% cellulose (2C), 4% cellulose (4C), 2% beet pulp (2BP), and 4% beet pulp (4BP). Ingredient composition of all diets included beef trimmings (94.7% - 96.7%; Central Nebraska Packing, Inc, North Platte, NE), Meat Complete vitamin and mineral premix (1.3%; Central Nebraska Packing, Inc), and fiber source [2-4%; cellulose (Solka Floc, International Fiber, North Towanda, NY) or beet pulp (Baltzell Agri Products, Omaha, NE)]. Water was provided *ad libitum*. In each period, animals were adapted to dietary treatments for 16 d prior to a 5-d collection period. During the collection period, food intake and fecal output were measured daily for digestibility determinations. Additionally, fresh fecal samples were collected for measurement of fecal characteristics.

Diet Composition, Apparent Total Tract Energy and Macronutrient Digestibility, and Fresh Fecal Characteristics

Diet, total fecal, and fresh fecal samples were collected, prepared for analyses, and analyzed according to methods described in Chapter 3. Diet and total fecal samples were analyzed for dry matter (DM), organic matter (OM), crude protein (CP), acid hydrolyzed fat, total dietary fiber (TDF; diet only), and gross energy (GE) concentrations. Metabolizable energy

(ME) was estimated using the equation (NRC, 2006): diet GE * GE digestibility – [0.77 * (diet CP)]. Fresh fecal pH and fecal scores were determined. Scoring was conducted using a 5 point scale as follows: 1 = hard, dry pellets; 2 = dry, well-formed stools; 3 = soft, moist, formed stool; 4 = soft, unformed stool; and 5 = watery, liquid that can be poured. Fresh fecal ammonia, short-chain fatty acid (SCFA), branched-chain fatty acid (BCFA), phenol, and indole concentrations were measured, and *Escherichia coli*, *Bifidobacterium* genus, *Lactobacillus* genus, and *Clostridium perfringens* were quantified.

Statistical Analysis

Data were analyzed using the Mixed Models procedure of SAS (SAS Inst., Cary, NC). The fixed effects of species, fiber type, and fiber concentration were tested and the interaction terms investigated. Period and cat were considered random effects. Differences among species were determined using a Fisher-protected LSD with a Tukey adjustment to control for experiment-wise error. A probability of $P < 0.05$ was accepted as statistically significant. Post hoc analysis of the linear effect of BW was conducted for DM, OM, fat, and GE digestibilities across all diets, and for CP digestibility, fecal score, fecal DM, and wet fecal output within fiber type. Reported pooled standard errors of the mean (SEM) were determined according to the Mixed Models procedure of SAS.

RESULTS

Diet Composition

Diet ingredient and macronutrient composition are presented in Table 4.2. Diets were similar in DM (23 to 25%), OM (92% DM), acid hydrolyzed fat (7 to 8% DM), and GE (5.2 to 5.3 kcal/g DM) concentrations. Crude protein concentration decreased (72 to 80% DM) with increasing TDF (7 to 15% DM). The TDF concentration of the cellulose-based diets contained

about 92 to 93% insoluble fiber and 7 to 8% soluble fiber, while the beet pulp-based diets contained 55 to 62% insoluble fiber and 38 to 46% soluble fiber.

Main Effects and Interaction of Fiber Type and Fiber Concentration

Fiber type and concentration had an impact on apparent total tract macronutrient digestibility, ME, and fecal characteristics. Data are presented in Table 4.3, Table 4.4, and Table 4.5, respectively. Food intake (g/d DM) did not differ due to fiber or level. Apparent total tract DM and OM digestibility was higher ($P \leq 0.05$) for cats fed BP compared to those fed C, and was higher ($P \leq 0.05$) for cats fed 2C compared to those fed 4C. Apparent total tract OM digestibility was also higher ($P \leq 0.05$) for cats fed 2BP compared to those fed 4BP. Apparent total tract CP and fat digestibilities were higher ($P \leq 0.05$) for cats fed C compared to those fed BP. Apparent total tract fat digestibility was also higher ($P \leq 0.05$) for cats fed 2% fiber compared to those fed 4% fiber. Apparent total tract GE digestibility was higher ($P \leq 0.05$) by cats fed 2BP, 4BP, and 2C compared to those fed 4C, and higher ($P \leq 0.05$) for cats fed 2BP and 2C compared to those fed 4BP. Increasing dietary fiber concentration decreased ($P \leq 0.05$) apparent total tract DM digestibility for cats fed C, but had no affect ($P > 0.05$) for cats fed BP. Increasing dietary fiber concentration decreased ($P \leq 0.05$) apparent total tract OM and GE digestibilities for cats, regardless of fiber type; however, the decrease was greater for cats fed C compared to those fed BP.

Digestible energy (kcal/g DM) and estimated ME (kcal/g DM) were higher ($P \leq 0.05$) for cats fed 2BP, 4BP, and 2C compared to those fed 4C, and higher ($P \leq 0.05$) for cats fed 2BP and 2C compared to those fed 4BP. Increasing dietary fiber concentration decreased ($P \leq 0.05$) digestible energy (kcal/g DM) and estimated ME (kcal/g DM), regardless of fiber type; however, the decrease was greater for cats fed C compared to those fed BP. Intake of ME based on

metabolic BW [kcal / (d · $BW^{0.75}$)] was not impacted by dietary fiber or concentration within species (Table 4.4).

Fecal output (g/d as-is) was higher ($P \leq 0.05$) for cats fed 4BP compared to those fed 2BP, 2C, and 4C, and higher ($P \leq 0.05$) for cats fed 2BP and 4C compared to those fed 2C (Table 4.5). Increasing dietary fiber concentration increased ($P \leq 0.05$) fecal output (g/d as-is) for cats, regardless of fiber type; however, the decrease was greater for cats fed C compared to those fed BP. Fecal output (g/d DM) was higher ($P \leq 0.05$) for cats fed 4C compared to those fed 2BP, 4BP, and 2C, and higher ($P \leq 0.05$) for cats fed 4BP compared to those fed 2BP. Fecal scores were higher ($P \leq 0.05$) for cats fed BP compared to those fed C, and higher ($P \leq 0.05$) for cats fed 4BP compared to those fed 2BP. Increasing dietary fiber concentration increased ($P \leq 0.05$) fecal scores for cats fed BP, but had no affect ($P > 0.05$) for cats fed C. Fecal DM was higher ($P \leq 0.05$) for cats fed C compared to those fed BP, and higher ($P \leq 0.05$) for cats fed 2% fiber compared to those fed 4% fiber. Compared to cats fed C, cats that were fed BP had lower ($P \leq 0.05$) fecal pH and higher ($P \leq 0.05$) fecal concentrations (umol/g DM) of ammonia, total SCFA, butyrate, and propionate, and higher ($P \leq 0.05$) fecal concentrations (CFU/g DM) of *Lactobacillus* and *Escherichia coli*. Fecal concentrations of acetate were higher ($P \leq 0.05$) for cats fed BP compared to those fed C, and higher ($P \leq 0.05$) for cats fed 4BP compared to those fed 2BP. The proportion of total SCFA as acetate was higher ($P \leq 0.05$) and that of butyrate lower ($P \leq 0.05$) for cats fed BP (73% acetate, 7% butyrate) compared to those fed C (69% acetate, 11% butyrate), while the proportion of propionate was not affected (20%). Fecal isovalerate concentrations were higher ($P \leq 0.05$) for cats fed 2BP compared to those fed 4BP, 2C, and 4C. Fecal valerate concentrations were higher ($P \leq 0.05$) for cats fed 2BP compared to those fed 2C and 4C. Increasing dietary fiber concentration decreased ($P \leq 0.05$) fecal BCFA

and isovalerate concentrations for cats fed BP, but had no affect ($P > 0.05$) for cats fed C. Fecal concentrations of the *Bifidobacterium* genus were higher ($P \leq 0.05$) for cats fed 2BP and 4BP compared to those fed 2C, and higher ($P \leq 0.05$) for cats fed 4BP compared to those fed 4C.

Impact of Species: Main Effect, Interaction with Fiber Type, and Interaction with Fiber Concentration

When BW was included as a covariate, food intake (g/d DM) was higher ($P \leq 0.05$) for CHE (718 g/d DM) compared to JAG (573 g/d DM; data not shown). Cheetahs had a higher ($P \leq 0.05$) apparent total tract DM digestibility compared to ST, and higher ($P \leq 0.05$) apparent total tract OM, fat, and GE digestibilities compared to MT and ST (Table 4.6). When fed BP, CHE had higher ($P \leq 0.05$) apparent total tract CP digestibility compared to MT and ST (Table 4.7). For JAG, MT, and ST, apparent total tract CP digestibility was higher ($P \leq 0.05$) for cats fed C compared to those fed BP. Digestibility decreased linearly ($P \leq 0.05$) with BW for apparent total tract DM, OM, fat, and GE. Apparent total tract CP digestibility decreased linearly ($P < 0.001$) with BW for cats fed BP, but not for cats fed C ($P = 0.306$). Metabolizable energy intake based on metabolic BW (kcal/g DM/kg $BW^{0.75}$) was greater ($P \leq 0.05$) for MT and ST compared to JAG (Table 4.4).

When fed BP, wet fecal output was higher ($P \leq 0.05$) for MT and ST compared to CHE and JAG (Table 4.7). When fed C, wet fecal output was higher ($P \leq 0.05$) for ST compared to CHE and JAG. When fed 2% fiber, wet and dry fecal outputs were higher ($P \leq 0.05$) for ST compared to CHE and JAG (Table 4.8). When fed 4% fiber, wet and dry fecal outputs were higher ($P \leq 0.05$) for MT and ST compared to CHE and JAG. For MT and ST, wet fecal output was higher ($P \leq 0.05$) for cats fed BP compared to those fed C, and higher ($P \leq 0.05$) for cats fed 4% fiber compared to those fed 2% fiber. For JAG, dry fecal output was higher ($P \leq 0.05$) for

cats fed 4% fiber compared to those fed 2% fiber. Wet fecal output decreased linearly ($P \leq 0.05$) with BW for cats fed BP and C; however, the decrease was greater ($P \leq 0.05$) for cats fed BP compared to those fed C.

When fed BP, ST had higher ($P \leq 0.05$) fecal scores (4.1) compared to CHE (3.4) and JAG (3.5; Table 4.7). When fed C, ST had higher ($P \leq 0.05$) fecal scores (3.3) compared to CHE (2.7) and JAG (2.0), and MT had higher ($P \leq 0.05$) fecal scores (3.0) compared to JAG. Fecal scores were lower (harder) than ideal (< 2.5) for JAG fed C, and higher (looser) than ideal (> 3.5) for JAG and MT fed 4BP and for ST fed both BP diets. When fed BP, CHE had higher ($P \leq 0.05$) fecal DM compared to MT and ST. When fed C, CHE and JAG had higher ($P \leq 0.05$) fecal DM (42%) compared to MT and ST. Fecal DM decreased linearly ($P \leq 0.05$) with BW for cats fed BP and C, while fecal scores increased linearly ($P \leq 0.05$) with BW.

When fed 2% fiber, ST had higher ($P \leq 0.05$) fecal concentrations of phenol, total BCFA, isovalerate, and valerate compared to CHE, JAG, and MT (Table 4.8). Siberian tigers fed 2% fiber had higher ($P \leq 0.05$) fecal phenol, total BCFA, isovalerate, and valerate concentrations compared to those fed 4% fiber. Fecal concentrations of the *Bifidobacterium* genus were higher ($P \leq 0.05$) for ST compared to CHE and MT, and higher ($P \leq 0.05$) for JAG compared to CHE (Table 4.6). Fecal concentrations of *Escherichia coli* were higher ($P \leq 0.05$) for JAG and ST compared to CHE. When fed diets containing cellulose, fecal concentrations of the *Lactobacillus* genus were higher ($P \leq 0.05$) for ST compared to CHE and MT. For JAG and MT, fecal concentrations of the *Lactobacillus* genus were higher ($P \leq 0.05$) for cats fed BP than those fed C (Table 4.7).

DISCUSSION

The majority of research related to raw meat diets in captive exotic felids has focused on the manipulation of protein sources, with little research on other dietary ingredients, including the effects of fiber source and concentration. Because of its carnivorous origins, relatively small colon (~20% of digestive tract length), and lack of cecum, cats have not been historically researched as it pertains to dietary fiber fermentation. In the domestic cat, inclusion of dietary fiber can increase colonic weight and mucosal cell activity, including enhanced mucosal tissue energetics and SCFA absorption (Bueno et al., 2000a; 2000b). These effects on colon weight and mucosal activity may be due to tactile response from distention or abrasion of gut surface, or by chemical response to the fermentative end-products produced by the microbial breakdown of fiber.

The primary fibers added to raw meat-based diets for captive exotic felids are beet pulp and microcrystalline cellulose. Beet pulp is a moderately fermentable, non-viscous fiber. It can be variable in composition, but is often high in pectin, cellulose, and hemicelluloses. Microcrystalline cellulose is a relatively non-fermentable, insoluble, non-viscous fiber.

Apparent Total Tract Macronutrient Digestibility

The authors are aware of no studies that have examined differing dietary fiber concentrations in captive exotic felid diets. For the most part, the differences reported herein for macronutrient digestibility between fiber types and concentrations are small and not likely to be physiologically significant regarding the ability of animals to obtain adequate concentrations of macronutrients and energy if taken into consideration when formulating diets.

The apparent total tract energy and macronutrient digestibility and ME data reported herein are likely partially explained by the nature of the fibers themselves (i.e., high DM and low

energy contents, low digestibilities, and varied fermentation profiles). For example, increasing the inclusion of low-fermentable fibers in place of highly digestible beef trimmings resulted in a decreased digestibility (DM, OM, and GE). Similar to other data, increasing wood cellulose concentration (0 to 5%) numerically decreased apparent total tract OM digestibility (86 vs. 81%), but had no effect on GE digestibility in domestic cats (Leibetseder, 1984). Increased dietary beet pulp inclusion (2.5% vs. 7.5%) decreased apparent total tract DM (89 vs. 86%), OM (92 vs. 89%) and GE (93 vs. 90%) digestibilities by dogs (Fahey et. al., 1990).

Additionally, the use of cellulose (less fermentable) vs. beet pulp (moderately fermentable) as the fiber source decreased OM digestibility, and resulted in increased CP and fat digestibilities. Vester et al. (2010a) also reported an increased CP digestibility in domestic and captive exotic felids fed a diet containing cellulose (horse meat-based) when compared to a diet containing beet pulp (beef-based); however, no fiber inclusion levels or TDF values were reported. Sunvold et al. (1995b) reported decreased apparent total tract CP digestibility (88% vs. 83%) by domestic cats fed cellulose- and beet pulp-containing diets (~11% TDF). A study performed by Kienzle et. al. (1991) reported decreased apparent total tract CP digestibility in diets containing fermentable fibers (i.e., wheat bran, horn meal, feather meal, etc.) when compared to diets containing no fiber diet or cellulose. The decreased apparent total tract CP digestibility of beet pulp-containing diets is likely due to increased fermentation (vs. cellulose), leading to increased bacterial protein production in the large bowel and underestimation of apparent CP digestibility.

Apparent total tract fat digestibility of all diets was lower than expected for raw meat diets; however, decreased fat digestibility (~90%) has been reported for captive exotic felids (Chapter 3) and domestic cats fed low-fat (< 10% fat) diets (Kane et al., 1981a). Because the

dietary fat concentration fed herein was low, any impact of fiber on endogenous fat excretion, fat digestion and absorption, and transit time may have impacted digestibility calculations greater than in high-fat diets. This may explain why differences were noted herein, but not in previous studies in domestic dogs and cats and captive exotic felids. Edwards et al. (2001) reported transit times of < 24 h for captive exotic felids (Turmenistan caracal and Amur leopard cat) fed raw meat diets containing either beet pulp (diet = 12.6 % TDF) or wood cellulose (diet = 17.1% TDF); however, because cats are most active at night, the actual time of defecation was not recorded and smaller differences in transit time may have been present but not recorded. Fahey et. al. (1990) reported a linear decrease in apparent total tract fat digestibility with increased beet pulp inclusion (0 to 12.5%) in dogs, while Leibetseder (1984) reported no differences in fat digestibility with increased wood cellulose inclusion (0 to 20%) in domestic dogs and cats. To our knowledge, no previous studies have evaluated the role / impact of fiber type on fat excretion or macronutrient digestion and absorption in captive exotic cats.

Apparent total tract macronutrient digestibility was altered by species. Digestibility appeared to decrease with BW; however, these data may have also been impacted by sex or age. All CHE utilized were young to middle-aged adults (3 to 8 y), while ST were older (8 to 18 y). CHE and JAG were predominantly male (3 male, 1 female), while the ST and MT were predominantly female (1 male, 3 female). A similar decrease in digestibility with BW has been noted for the TDF fraction in captive exotic cats (Vester et al., 2010a; Clauss et. al., 2010); however, TDF digestibility was not measured herein. It is worth noting that differences in apparent total tract nutrient digestibilities among species and/or with BW may not reflect differences in true digestibility. The decrease in apparent CP digestibility with BW, for

example, only occurred in cats fed BP, indicating that larger cats may be more sensitive to fermentable fiber inclusion and that changes in digestibility were due to bacterial fermentation.

Fecal Characteristics

Understanding the interactions between fiber type, fiber concentration, and species, and how fecal characteristics are impacted is important. These data aid in developing species-specific diet formulations, so animal health and cat management in zoos can be optimized. Production of SCFA (butyrate, in particular) is considered beneficial, while the production of putrefactants in humans and pets is considered negative. Researchers should strive to identify diet formulas that are able to achieve these responses in order to promote health. Butyrate is the main fuel source of colonocytes, and high concentrations have been linked to increased colonocyte proliferation and decreased inflammation. Increased fecal BCFA, phenol, and indole concentrations are indicators of increased protein fermentation. The products of protein fermentation are odiferous compounds that make animal management in zoos difficult; however, the effects of long-term exposure to these compounds in felines have not been examined.

Fecal pH, scores, and fermentative end-product concentrations were similar to previous reports in captive exotic cats fed raw meat-based diets containing either cellulose or beet pulp fibers (Chapter 3; Vester et. al., 2008; 2010a; 2010b). The concentrations of fecal fermentative end-products in exotic felid species living in the wild are unknown. DePauw et al. (2012), however, measured these compounds in captive cheetahs fed whole prey rabbits (61% CP) or a raw beef-based diet (86% CP) containing no supplemental fiber. Fecal acetate, propionate, and BCFA concentrations in cheetahs fed cellulose herein were numerically higher compared to those fed whole rabbit in that study (353 vs. 171 umol acetate/g DM, 79 vs. 36 umol propionate/g DM, and 20 vs. 4.35 umol total BCFA/g DM). Fecal butyrate concentrations were

similar (39 vs. 33 umol butyrate/g DM) between these studies. Fecal phenol and indole concentrations in cheetahs fed whole rabbits (DePauw et al., 2012) were similar to those for cheetahs fed cellulose and beet pulp in the current study (1.2 vs. 1.4 umol phenol/g DM; 1.1 vs. 1.2 umol indole/g DM). To properly analyze the impact that whole prey diets may have on fecal fermentative end-products and compare them to fiber supplementation strategy, a direct comparison is needed.

Because cellulose is non-fermentable, fecal fermentative end-product concentrations of cats fed this fiber source may be mainly attributed to protein fermentation. Fecal fermentative end-product concentrations of cats fed BP, however, are likely due to a combination of carbohydrate and protein fermentation. The impacts of fiber source and type on gastrointestinal and host health are difficult to interpret because fecal fermentative end-products are affected by multiple factors, including the dilution of fecal compounds, changes in transit time, and alterations in production or absorption. Because beet pulp has a greater fermentability and water-holding capacity, the decreased fecal pH and DM, and increased wet fecal output, fecal scores, and fecal SCFA and ammonia concentrations noted in cats fed this fiber were expected. Fecal fermentative end-product concentration differences due to fiber type may have been increased even more due to the increased fecal bulk observed for cats fed cellulose, which would have diluted these fecal compounds. Middelbos et al. (2007) also reported decreased fecal SCFA in dogs fed cellulose-containing diets compared to diets containing no supplemental fiber. Fecal SCFA concentrations also were decreased in cheetahs fed whole prey rabbits (high in fecal bulk, including bone, skin, and hair) compared to a raw beef diet with no supplemental fiber (DePauw et al., 2012).

The increased fecal BCFA concentrations for cats fed beet pulp vs. cellulose may have been due to many factors, and has been reported in exotic cats fed similar diets in the past (Vester et al., 2010a). Additionally, Middelbos et al. (2007) reported increased fecal BCFA for dogs fed a diet containing cellulose (1%) + fructooligosaccharides (1.5%), which is a highly fermentable prebiotic, compared to those fed cellulose (2.5%) alone, while fecal BCFA concentrations for dogs fed no supplemental fiber (0%) or beet pulp (2.5%) were intermediate.

The role of dietary fiber may be different depending on the captive exotic cat species. The larger cats, namely MT and ST, had larger, wetter and looser stools (i.e., increased wet fecal output, fecal scores, and decreased fecal DM) compared to JAG and CHE. For ST, it appears that higher fiber inclusion (4%) may be important for modulating protein fermentation and decreasing fecal putrefactive compounds (i.e., phenol and BCFA). Increased defecation, and wetter and looser stools, also have been noted in large-breed vs. small-breed dogs (Zentek and Meyer, 1995). Research has shown that large-breed compared to small breed-dogs have increased intestinal permeability and lower absorption of electrolytes, including sodium, which results in higher fecal osmolality and decreased fecal quality (Hernot et al., 2004; 2009). Additionally, poor fecal quality for larger-breed dogs has been related to longer mean total transit time and, more specifically, longer large intestinal transit time when compared to smaller breeds (Hernot et al., 2005; 2006). These mechanisms have not been evaluated in large vs. small species of cats, but may have contributed to the results observed in the current study.

CONCLUSIONS

Our primary objective was to evaluate the effects of commonly fed dietary fibers on digestibility and fecal characteristics of captive exotic cats. These data indicate that a blend of beet pulp and cellulose may be the best choice as it pertains to animal health and zoo

management. For example, utilizing 2% beet pulp + 2% microcrystalline cellulose might provide the benefits of carbohydrate fermentation (i.e., increased fecal SCFA concentrations from beet pulp inclusion) and 4% fiber (i.e., fecal bulk and dilution of fecal putrefactive compounds) without the increase in wet fecal weight due to 4% beet pulp inclusion. The interactions noted among species and fiber indicate that different diets may be appropriate for cats of different sizes. Given that larger cats were more sensitive to the inclusion of fermentable fibers, and providing fecal bulk may be more important to decrease the higher concentrations of fecal putrefactive compounds, a blend with higher concentrations of cellulose may be needed for large vs. small cats.

Because fiber-related differences reported herein were similar to those reported for commercially available horse- and beef-based diets by Vester et al. (2010a), our data indicate that those differences were likely due to dietary fiber source rather than protein source. Dietary CP concentrations, and fiber*protein interactions also may affect nutrient digestibility and fecal characteristics, however. Additional research, focused on the long-term effects of diets resulting in “beneficial” and “detrimental” fecal fermentative end-products, identifying the optimal fiber blend for all captive exotic felids, or the evaluation of interactions between protein and fiber may be worthwhile.

TABLES

Table 4.1. Sex, body weight, body condition score (BCS), and age of captive exotic felids

Species	Sex	BW[1] (kg)	BCS[2]	Age (y)
Cheetah	F	39	3.0	2.9
	M	41	3.5	7.7
	M	41	3.5	7.3
	M	43	3.0	7.3
Jaguars	F	59	4.0	8.3
	M	59	3.0	19.8
	M	57	3.0	6.8
	M	63	2.5	3.0
Malayan tigers	F	88	3.0	15.6
	F	98	3.0	15.6
	F	103	2.5	4.2
	M	103	3.0	8.8
Siberian tigers	F	98	3.5	18.0
	F	103	2.0	8.7
	F	123	2.5	13.7
	M	148	2.5	13.1

[1]Determined at most recent medical examination.

[2] BCS = Body condition score; determined on a 5-point scale with 1 = emaciated, 3 = ideal, and 5 = obese. All BCS were determined with special consideration of the species being evaluated (e.g., structural differences in body frame).

Table 4.2 Ingredient and chemical composition of raw meat diets fed to domestic and captive exotic felids

	Beet Pulp		Cellulose	
Item	2%	4%	2%	4%
Dry matter (DM), %	23.0	24.1	23.4	24.7
Organic matter, % DM	92.3	91.7	91.6	92.3
Crude protein, % DM	79.3	75.7	76.6	72.2
Acid hydrolyzed fat, % DM	7.7	7.4	7.6	7.1
Total dietary fiber, % DM	6.9	10.5	10.0	15.1
Soluble	2.6	4.7	0.7	1.2
Insoluble	4.3	5.8	9.3	13.9
Gross energy, kcal/g DM	5.3	5.2	5.3	5.2

Ingredient composition for all diets: 94.7 to 96.7% beef trimmings (Central Nebraska Packing, Inc), 2 to 4% fiber source [cellulose (Solka Floc, International Fiber, North Towanda, NY) or beet pulp (Baltzell Agri Products, Omaha, NE)], feline vitamin premix (vitamin A acetate, thiamine mononitrate, d-calcium pantothenate, mineral oil, d-biotin, pyridoxine hydrochloride, vitamin D3 supplement), taurine, feline mineral premix (zinc oxide, manganous oxide, copper oxide, mineral oil, sodium selenite, calcium iodate).

Table 4.3 Apparent total tract energy and macronutrient digestibility of raw meat diets fed to cheetahs (*Acinonyx jubatus*), jaguars (*Panthera onca*), Malayan tigers (*Panthera tigris corbetti*), and Siberian tigers (*Panthera tigris altaica*)

Item	Beet Pulp		Cellulose			P - value		
	2%	4%	2%	4%	SEM	FIB	CONC	FIB* CONC
Dry matter	82.3[b]	80.4[b]	81.9[b]	76.7[a]	0.90	0.006	<0.001	0.023
Organic matter	87.4[c]	84.8[b]	85.9[bc]	80.1[a]	0.62	<0.001	<0.001	0.005
Crude protein	93.3[a]	93.0[a]	95.1[b]	95.1[b]	0.33	<0.001	0.510	0.518
Acid hydrolyzed fat	83.5[a]	81.9[a]	88.0[b]	86.1[b]	0.95	<0.001	0.014	0.805
Gross energy	87.6[c]	85.5[b]	87.6[c]	83.1[a]	0.59	0.018	<0.001	0.021

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

Table 4.4 Metabolizable energy of raw meat diets fed to cheetahs (*Acinonyx jubatus*), jaguars (*Panthera onca*), Malayan tigers (*Panthera tigris corbetti*), and Siberian tigers (*Panthera tigris altaica*)

Item	Beet Pulp		Cellulose			P - value		
	2%	4%	2%	4%	SEM	FIB	CONC	FIB* CONC
Digestible energy (kcal/g DM)	4.63[c]	4.45[b]	4.64[c]	4.30[a]	0.04	0.023	<0.001	0.012
Metabolizable energy[1] (kcal/g DM)	4.06[c]	3.91[b]	4.08[c]	3.77[a]	0.04	0.042	<0.001	0.010
ME intake (kcal/g DM/kg $BW^{0.75}$)					3.00	0.686	0.466	0.103
Cheetah[xy]	85.0	86.8	84.8	82.5				
Jaguar[x]	67.7	70.0	73.3	67.5				
Malayan tiger[y]	95.9	92.8	98.2	94.7				
Siberian tiger[y]	100.4	103.6	102.0	102.9				

[a-c] Means within a row lacking a common superscript letter are different ($P \leq 0.05$).
[x-y] Means for species lacking a common superscript letter are different ($P \leq 0.05$).
[1] Metabolizable energy = digestible energy – (0.77 x crude protein).

Table 4.5 Fecal characteristics of captive exotic felids [n = 4 per spp.; cheetahs (*Acinonyx jubatus*), jaguars (*Panthera onca*), Malayan tigers (*Panthera tigris corbetti*), and Siberian tigers (*Panthera tigris altaica*)] fed raw meat diets

	Beet Pulp		Cellulose			P - value		
Item	2%	4%	2%	4%	SEM	FIB	CONC	FIB* CONC
Fecal output, g /d as-is	474.0^{b}	693.7^{c}	298.5^{a}	413.4^{b}	44.93	<0.001	<0.001	0.020
Fecal output, g /d DM[1]	111.2^{a}	130.4^{b}	113.4^{ab}	149.2^{c}	12.44	0.028	<0.001	0.079
Fecal score	3.4^{b}	3.9^{c}	2.7^{a}	2.8^{a}	0.18	<0.001	<0.001	0.001
Fecal DM, %	24.4^{b}	19.6^{a}	40.3^{d}	37.5^{c}	0.89	<0.001	<0.001	0.160
pH	6.8^{a}	6.2^{a}	7.5^{b}	7.6^{b}	0.19	<0.001	0.124	0.085
Ammonia, umol/g DM	373.1^{b}	367.4^{b}	280.9^{a}	245.6^{a}	38.98	0.007	0.578	0.692
Phenol, umol/g DM	2.1	1.4	1.7	1.5	0.24	0.506	0.084	0.358
Indole, umol/g DM	1.6	1.5	1.3	1.3	0.20	0.116	0.781	0.899
SCFA[1], umol/g DM	1036.1^{b}	1342.9^{b}	429.2^{a}	486.5^{a}	95.59	<0.001	0.067	0.202
Acetate	748.3^{b}	1021.3^{c}	301.4^{a}	344.3^{a}	71.34	<0.001	0.035	0.118
Butyrate	84.1^{b}	84.4^{b}	41.0^{a}	47.1^{a}	9.40	<0.001	0.734	0.758
Propionate	203.8^{b}	237.2^{b}	86.9^{a}	95.1^{a}	19.71	<0.001	0.299	0.528
BCFA[2], umol/g DM	41.2^{b}	29.5^{ab}	20.8^{a}	27.1^{a}	4.13	0.003	0.444	0.017
Isobutyrate	1.12	1.2	0.7	1.2	0.36	0.516	0.376	0.456
Isovalerate	23.3^{b}	14.7^{a}	11.5^{a}	15.1^{a}	2.54	0.013	0.262	0.010
Valerate	17.0^{b}	13.8^{ab}	8.8^{a}	11.0^{a}	1.66	<0.001	0.745	0.071
Microbes, log CFU[1]/g DM								
Lactobacillus genus	10.9^{b}	11.0^{b}	10.5^{a}	10.5^{a}	0.09	<0.001	0.792	0.603
Bifidobacterium genus	6.4^{bc}	6.8^{c}	5.8^{a}	6.2^{ab}	0.17	<0.001	0.005	0.827
Clostridium perfringens	10.2	10.6	10.1	10.3	0.23	0.158	0.082	0.426
Escherichia coli	10.9^{ab}	10.9^{b}	10.2^{a}	10.8^{ab}	0.22	0.043	0.103	0.113

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

[1] SCFA = acetate + butyrate + propionate.

[2] BCFA = isobutyrate + isovalerate + valerate.

[3] CFU = colony forming unit.

Table 4.6 Impact of species on macronutrient and energy digestibility values and fecal characteristics of captive exotic felids fed raw meat diets[1]

Item	Species				SEM	P-value
	Cheetah	Jaguar	Malayan Tiger	Siberian Tiger		
Digestibility						
Dry matter, %	83.1[b]	81.4[ab]	78.7[ab]	78.0[a]	1.34	0.038
Organic matter, %	87.4[b]	85.0[ab]	82.6[a]	83.2[a]	0.85	0.001
Acid hydrolyzed fat, %	88.8[b]	85.6[ab]	84.9[ab]	84.0[a]	0.97	0.014
Gross energy	88.6[b]	86.4[ab]	84.0[a]	84.8[a]	0.81	0.002
Fecal characteristics						
Ammonia, umol/g DM	302.9[ab]	200.8[a]	370.2[b]	393.1[b]	38.59	0.003
Bifidobacterium genus, log CFU[2]/g DM	5.9[a]	6.4[bc]	6.2[ab]	6.8[c]	0.17	< 0.001
Escherichia coli, log CFU/g DM	10.3[a]	11.0[b]	10.6[ab]	11.0[b]	0.22	0.012

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

[1] n = 4 per species.

[2] CFU = colony forming unit.

Table 4.7 Fecal characteristics affected by species*fiber type interactions[1]

Item	Fiber		SEM	P - value		
	Beet Pulp	Cellulose		SPP	FIB	SPP* FIB
Fecal output, g /d as-is			83.66	<0.001	<0.001	<0.001
Cheetah	186.5^{x}	156.8^{x}				
Jaguar	316.4^{x}	184.0^{x}				
Malayan tiger	777.2^{by}	486.0^{axy}				
Siberian tiger	1055.3^{by}	597.0^{ay}				
CP Digestibility, %			0.54	0.196	<0.001	0.003
Cheetah	95.1^{y}	94.9				
Jaguar	93.5^{axy}	95.7^{b}				
Malayan tiger	92.8^{axy}	94.7^{b}				
Siberian tiger	92.5^{ax}	95.1^{b}				
Fecal Score			0.25	0.004	<0.001	<0.001
Cheetah	3.4^{bx}	2.7^{ay}				
Jaguar	3.5^{bx}	2.0^{ax}				
Malayan tiger	3.8^{bxy}	3.0^{ayz}				
Siberian tiger	4.1^{by}	3.3^{az}				
Fecal DM			1.24	<0.001	<0.001	0.016
Cheetah	25.9^{ay}	42.3^{by}				
Jaguar	21.4^{axy}	42.2^{by}				
Malayan tiger	20.7^{ax}	35.5^{bx}				
Siberian tiger	20.1^{ax}	35.7^{bx}				
Lactobacillus genus, log CFU[2]/g DM			0.12	0.090	<0.001	0.037
Cheetah	10.8	10.6^{xy}				
Jaguar	11.0^{b}	10.2^{ax}				
Malayan tiger	11.0^{b}	10.4^{axy}				
Siberian tiger	11.0	10.7^{y}				

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

$^{x-y}$ Means for species lacking a common superscript letter are different ($P \leq 0.05$).

[1] n = 4 per species.

Table 4.8 Fecal characteristics affected by species*fiber concentration interactions[1]

Item	Fiber Concentration		SEM	P - value		
	2%	4%		Species	CONC	Species* CONC
Fecal output, g /d as-is			83.66	<0.001	<0.001	0.003
Cheetah	149.0^{x}	194.4^{x}				
Jaguar	190.4^{x}	310.0^{x}				
Malayan tiger	500.6^{axy}	762.6^{by}				
Siberian tiger	705.0^{ay}	947.3^{by}				
Fecal output, g /d DM[1]			23.89	<0.001	<0.001	0.028
Cheetah	51.7^{x}	61.6^{x}				
Jaguar	59.4^{x}	81.2^{x}				
Malayan tiger	139.1^{axy}	189.4^{by}				
Siberian tiger	199.0^{y}	227.0^{y}				
Phenol, umol/g			30.61	0.022	0.084	0.002
Cheetah	128.8^{x}	160.9				
Jaguar	107.2^{x}	123.4				
Malayan tiger	155.9^{x}	158.0				
Siberian tiger	316.1^{by}	111.5^{a}				
Total BCFA, umol/g			5.35	<0.001	0.444	0.002
Cheetah	24.8^{x}	34.1				
Jaguar	16.4^{x}	19.9				
Malayan tiger	26.7^{x}	31.5				
Siberian tiger	56.0^{by}	27.7^{a}				
Isovalerate, umol/g			3.30	<0.001	0.262	0.001
Cheetah	13.0^{x}	18.3				
Jaguar	8.4^{x}	10.1				
Malayan tiger	14.4^{x}	16.9				
Siberian tiger	33.7^{by}	14.4^{a}				
Valerate, umol/g			2.16	0.003	0.745	0.006
Cheetah	11.5^{x}	15.4				
Jaguar	7.3^{x}	9.0				
Malayan tiger	11.5^{x}	13.9				
Siberian tiger	21.4^{by}	11.4^{a}				

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

$^{x-y}$ Means for species lacking a common superscript letter are different ($P \leq 0.05$).

[1]n = 4 per species.

CHAPTER 5: CHEMICAL ANALYSIS OF WHOLE CHICKS, GROUND WHOLE CHICKEN, A CHICKEN-BASED CANNED DIET, AND A CHICKEN-BASED EXTRUDED DIET AND THEIR EFFECTS ON APPARENT TOTAL TRACT MACRONUTRIENT DIGESTIBILITY, N BALANCE, AND BLOOD METABOLITES IN AFRICAN WILDCATS AND DOMESTIC CATS

ABSTRACT

Because it often is not possible to mimic natural feeding behaviors of domestic and captive exotic felids (i.e., feeding live prey), other feeding strategies are needed. Feeding of whole prey is common for both nutritive and enrichment purposes. Although the behavioral and ethical implications of feeding whole prey have been widely discussed, there is a paucity of information on whole prey nutritive value. Our objective was to evaluate the effects of feeding 1 to 3 d-old chicks (WHO), ground whole chicken (GRO), a chicken-based canned diet (CAN), and a chicken-based extruded diet (EXT) on apparent total tract energy and macronutrient digestibility by African wildcats (n = 4) and domestic cats (n = 11), and N balance and blood metabolites for domestic cats. Chemical analysis revealed that dietary Cu and Mn concentrations in GRO and WHO were lower than that recommended for adult cats by AAFCO (2012). Additionally, WHO was positive for *Salmonella* and *Escherichia coli*. Diet influenced apparent total tract macronutrient digestibilities, but values were similar between species. Apparent total tract OM and GE digestibilities were higher ($P \leq 0.05$) by African wildcats fed GRO (94% and 95%) compared to those fed CAN (87% and 89%), EXT (86% and 86%), or WHO (85% and 83%). Apparent OM and GE digestibilities were higher ($P \leq 0.05$) by cats fed CAN (86% and 88%), EXT (88% and 88%), and GRO (94% and 95%) compared to those fed WHO (83% and 83%), and higher ($P \leq 0.05$) by cats fed GRO compared to those fed CAN and EXT. All diets maintained BW and N balance. Many blood metabolites were modified by diet, but most

remained within reference ranges for domestic cats. Serum cholesterol was elevated above reference ranges for cats fed WHO, and greater ($P \leq 0.05$) than cats consuming the CAN, EXT, and GRO. Serum creatinine concentrations were above the reference range and higher ($P \leq 0.05$) for cats fed GRO compared to those fed CAN or WHO. In conclusion, whole prey chicks had digestibilities that were less than those of commercial canned and extruded diets, while ground whole chicken had a greater digestibility than commercial diets. All diets maintained BW and N balance. However, because of the nutrient deficiencies noted in whole prey items, they should only be included as part of a properly balanced diet.

INTRODUCTION

In the wild, smaller felids (e.g., feral cats, African wildcats, sand cats) typically eat rodents, other small mammals, reptiles, and birds. Because it is often not possible or desirable to mimic natural feeding behaviors of domestic and captive exotic felids (i.e., feeding live prey), other feeding strategies are needed.

For domestic cats, there are a multitude of diet options for a pet owner to choose from, including commercially available extruded and canned diets that are more traditional, unconventional diets (e.g., vegetarian, natural, organic, and raw diets) that have recently increased in popularity, and homemade diets such as raw meat-based and whole prey diets.

For small captive exotic felids, raw meat-based and whole prey diets are more traditional; however, they may increase risk of bacterial contamination to the cats and their keepers (Clyde et al., 1997; Crissey et al., 2001). Canned and extruded diets have been considered to be safe alternatives for small exotic felids (Crissey et al., 1997; Vester et al., 2010b).

In the zoo setting, whole prey often are fed as enrichment, with the aim of encouraging species typical behavior, specifically increasing the time and energy spent finding and

consuming food. However, there is a paucity of information on the nutritive value of whole prey options. Specifically, little research has been done to evaluate the nutrient composition or effects on apparent total tract digestibility of whole prey diets by cats. The authors are aware of only two studies in which values for macronutrient digestibility of ground whole prey were measured in domestic cats (Fekete et al., 2001; 2004), and one study that reported macronutrient digestibility of five whole prey species in ocelots (Bennett et. al., 2010). None, however, have compared the effects of whole prey to those of traditional canned and extruded diet types.

Our primary objective was to evaluate the effects of whole chicks (WHO), ground whole chicken (GRO), a chicken-based canned diet (CAN), and a chicken-based extruded diet (EXT) on apparent total tract energy and macronutrient digestibility by captive African wildcats and domestic cats. Our secondary objective was to identify any changes in N balance and blood metabolites of domestic cats fed these diet types.

MATERIALS AND METHODS

All animal procedures were approved by the University of Illinois and Henry Doorly Zoo Institutional Animal Care and Use Committees prior to animal experimentation.

Diets

Animals were randomized in a cross over design to one of four chicken-based dietary treatments: WHO (Rodent Pro, Inglefield, IN); GRO (My Pet Carnivore, Indianapolis, IN); CAN (Zupreem® Exotic Felid Canned Diet, Premium Nutritional Products Inc, Shawnee, KS); and EXT (Iams® ProActive Health™ Adult Original with Chicken, P&G Petcare, Cincinnati, OH).

Study 1: African Wildcats

Four African wildcats (AWC) were fed to maintain BW (mean BW = 3.8 ± 0.3 kg; mean age = 6.1± 0.6 y). African wildcats were housed individually in concrete floor enclosures

maintained by the Henry Doorly Zoo in Omaha, NE. Animals were adapted to dietary treatments for 16 d prior to a 4-d collection period. During the collection period, food intake and fecal output were measured daily and used for apparent total tract energy and macronutrient digestibility and metabolizable energy (ME) calculations.

Study 2: Domestic Cats

Eleven domestic shorthair cats (DOM) were fed to maintain BW and body condition score (BCS) (mean age = 5.3 $\pm$ 0.04 y; mean BW= 4.5 $\pm$ 0.4 kg; mean BCS = 5.0 on a 9-point scale). Domestic cats were housed individually in stainless steel cages (0.61 m x 0.61 m x 0.61 m) at the University of Illinois in a temperature- (21^{o}C) and light-controlled (14 h light:10 h dark) room. Animals were adapted to dietary treatments for 16 d prior to a 5-d collection period. During the collection period, food intake, urine output, and fecal output were measured daily and used for digestibility, N balance, and ME calculations. On the final day of the collection period, blood was collected for serum chemistry measurements according to the methods described in Chapter 3.

Diet, Fecal and Urine Analyses

Diet, total fecal, and total urine samples were collected, handled, and analyzed according to methods described in Chapter 3. Diet and total fecal samples were analyzed for dry matter (DM), organic matter (OM), crude protein (CP), acid hydrolyzed fat, and GE concentrations. In addition, diet samples from Study 1 were sent to Midwest Laboratories (Omaha, NE) for mineral analysis (AOAC 985.01) and microbial evaluation. Fecal samples were scored daily on a scale from 1 to 5 as described in Chapter 3. Urinary CP was measured. Metabolizable energy was estimated using the equation: (GE Intake * GE digestibility) – [0.77 * (dietary CP)].

Statistical Analysis

For each study, data were analyzed using the Mixed Models procedure of SAS (SAS Inst., Cary, NC). The fixed effect of diet was tested. Period and cat were considered random effects. Differences were determined using a Fisher-protected LSD with a Tukey adjustment to control for experiment-wise error. A probability of $P < 0.05$ was accepted as statistically significant. Reported pooled standard errors of the mean (SEM) were determined according to the Mixed Models procedure of SAS.

RESULTS

Diets

Ingredient and macronutrient composition was variable among dietary treatments (Table 5.1, Table 5.2, and Table 5.3). Because of the vast differences in ingredient and nutrient composition and processing methods among the diets tested, the effects of treatment may only be attributed to the diet as a whole. The DM, OM, CP, fat, and GE concentrations of CAN, EXT and GRO dietary treatments were similar across studies. The WHO were more variable, however, with that fed to AWC having slightly higher CP (76%) and lower fat (16%) concentrations compared to the WHO fed to DOM (72% and 20%, respectively).

Mineral concentrations of CAN and EXT were greater than or equal to recommendations for domestic cats (AAFCO, 2012). Mn and Cu concentrations in the GRO and WHO, however, were lower than recommended for adult domestic cats [7.5 mg Mn/kg DM; and 5 mg Cu/kg DM (AAFCO, 2012)]. Additionally, the GRO had lower K and Na concentrations than that recommended for adult domestic cats [0.6 % K; 0.2% Na (AAFCO, 2012)]. The CAN and EXT diets tested negative or were below detectable limits for all microbial tests (Table 5.4). The GRO and WHO, however, had aerobic plate counts of 1.1 million and 2.4 million colony

forming units (CFU) /g, respectively. The WHO also had >2000 CFU/g total coliforms and *E. coli*, and tested positive for salmonella (at least 1 organism / 25 g). The GRO had a mold count of 1940 CFU / g. These data confirm the pathogen exposure that exists in feeding raw and whole prey diets.

Study 1: African Wildcats

Food intake and fecal output data for African wildcats are presented in Table 5.5. Diets were fed to maintain BW, but intake and output (g / d as-is) varied greatly with treatment. Apparent total tract DM digestibility (81 to 85%) was not impacted by treatment. Apparent total tract OM and GE digestibility were higher ($P \leq 0.05$) for cats fed GRO compared to those fed CAN, EXT, or WHO. Apparent total tract CP digestibilities was higher ($P \leq 0.05$) for cats fed GRO compared to those fed EXT. Cats fed CAN and WHO had intermediate apparent total tract CP digestibilities that were not different from GRO or EXT. Apparent total tract fat digestibility was higher ($P \leq 0.05$) for cats fed CAN, GRO, or EXT compared to those fed WHO, and higher ($P \leq 0.05$) for cats fed GRO compared to those fed EXT. Digestible energy and estimated ME were higher ($P \leq 0.05$) for CAN and GRO compared to EXT and WHO; however, ME intake did not differ ($P > 0.05$) among treatments.

Study 2: Domestic Cats

Food intake and fecal output data for DOM are presented in Table 5.6. Diets were fed to maintain BW, but intake and output (g/d as-is) varied greatly with treatment. Apparent total tract DM digestibility was higher ($P \leq 0.05$) for cats fed EXT and GRO compared to those fed CAN and WHO. Apparent OM and GE digestibilities were higher ($P \leq 0.05$) for cats fed CAN, EXT, or GRO compared to those fed WHO, and higher ($P \leq 0.05$) for cats fed GRO compared to those fed CAN or EXT. Apparent total tract CP digestibility was higher ($P \leq 0.05$) for cats fed GRO

compared to those fed CAN, EXT, or WHO. Apparent total tract fat digestibility was higher ($P \leq 0.05$) for cats fed CAN, EXT, and GRO compared to those fed WHO, and higher ($P \leq 0.05$) for cats fed CAN and GRO compared to those fed EXT.

Digestible energy and estimated ME were higher ($P \leq 0.05$) for CAN, GRO, and WHO compared to EXT, higher ($P \leq 0.05$) for cats fed CAN and GRO compared to those fed WHO, and higher ($P \leq 0.05$) for cats fed GRO compared to those fed CAN. Estimated ME intake (as-is and based on metabolic BW) was higher ($P \leq 0.05$) for cats fed CAN, EXT, or GRO compared to those fed WHO, and higher ($P \leq 0.05$) for cats fed CAN compared to those fed EXT and GRO.

Nitrogen intake was higher ($P \leq 0.05$) for cats fed CAN and WHO compared to those fed EXT and GRO, and higher ($P \leq 0.05$) for cats fed WHO compared to those fed CAN (Table 5.7). Fecal N was higher ($P \leq 0.05$) for cats fed CAN, EXT, or WHO compared to those fed GRO, and higher ($P \leq 0.05$) for cats fed CAN or WHO compared to those fed EXT. Absorbed and urinary N were higher ($P \leq 0.05$) for cats fed CAN, WHO, or GRO compared to those fed EXT, and higher ($P \leq 0.05$) for cats fed WHO compared to those fed CAN or GRO. The total urinary volume excreted was higher ($P \leq 0.05$) for cats fed WHO (91 mL/d) compared to those fed CAN, EXT, or GRO (52, 54 and 54 mL/d, respectively).

Reference ranges (provided by the Clinical Pathology Laboratory at the University of Illinois) and blood metabolite data are presented in Table 5.8. Cats fed all dietary treatments had serum creatinine and cholesterol concentrations above the reference range. Serum creatinine concentrations were higher ($P \leq 0.05$) for cats fed GRO compared to those fed CAN and WHO. Serum cholesterol concentrations were higher ($P \leq 0.05$) for cats fed WHO compared to those fed CAN, EXT, or GRO. Dietary treatment also impacted serum concentrations of alanine

aminotransferase, glucose, urea nitrogen, total protein, ALP, albumin, Na, P, non-esterified fatty acids, and triglycerides; however, all values remained within reference ranges.

DISCUSSION

Even though they are commonly fed, whole prey diets for captive exotic felids and domestic cats have received little research attention pertaining to their nutritional quality. There are many potential risks to feeding whole prey, including health problems that arise from the inclusion of feeding raw bones, potential for nutritional inadequacy, and bacterial contamination present in most raw animal products. Research is needed to highlight the potential advantages and disadvantages of whole prey feeding, including compositional analysis, acceptability, and apparent total tract macronutrient and energy digestibilities of whole prey items. These data are needed to allow for educated decisions regarding whole prey feeding. Our objective was to evaluate commercially available whole prey chicken diets (GRO and WHO) and compare them to traditional cat diets commonly fed to small captive exotic and domestic cats (EXT and CAN).

Although the traditional commercial diets are nutritionally complete foods with well-defined nutrient composition, concerns have been raised about the role of dry diets in obesity, diabetes, and renal diseases, and the role of canned diets in periodontal diseases. A decreased dietary protein:carbohydrate ratio has been suggested as a contributor of obesity in many species (Simpson and Raubenheimer, 2005); however, there is little research on this topic in felids (Vester et al., 2009). The high energy density of dry diets (kcal ME/g as-is) is thought to contribute to the obesity epidemic, because gut fill is smaller. Reports on the correlation between feeding high-carbohydrate dry diets and obesity/diabetes mellitus in domestic cats are conflicting, however (Singerland, 2005; Scarlett et al., 1998).

Compared to dry diets, animal prey are high in moisture and protein, and low in digestible carbohydrate. Commercial canned diets are usually low in digestible carbohydrates [< 10% ME from nitrogen free extract (NFE)]. The EXT diet fed herein was indeed low in moisture (8%) and high in carbohydrate (33% ME from NFE). The canned diet and whole prey diets, GRO and WHO, were all higher in moisture (60, 70, and 77%, respectively) and lower in digestible carbohydrates (8, 6, and 0% of ME from NFE, respectively) than EXT. The WHO had a very high protein concentration (76%); however, the protein concentration in GRO (43%) was similar to CAN (46%) and EXT (36%).

There are also potential implications pertaining to dry diets, water intake, and urinary tract health. Higher total water intake increases urine volume, decreases urine saturation, and decreases the risk of urinary tract diseases in cats (NRC, 2006). When fed high moisture diets (~30 % DM), the cat does not need to drink additional water to survive (Caldwell, 1931; Kane et al., 1981b; Prentiss et al., 1959). Although diet-related water intake (DWI) was lower in cats fed EXT (4 mL/d), the urine volume excreted (52 to 54 mL) was similar for cats fed EXT, CAN (87 mL DWI) and GRO (105 mL DWI). This indicates that cats fed the CAN and GRO likely did not greatly exceed their water needs; however, we did not directly measure total water intake, so care should be taken when interpreting these results. For cats fed WHO, DWI exceeded water needs and, thus, a larger volume of urine was produced (91 mL). Given the unique ingredient and nutrient composition of whole prey diets, research on urine saturation criteria is needed. If cats fed whole prey diets consistently have higher DWI and urine volume, whole prey diets may be beneficial.

Periodontal disease plagues both domestic and captive exotic cats, and can cause secondary adverse effects on general health (Watson, 1994; Haberstroth et al., 1984). The soft

texture of canned and minced meat diets provides less abrasion or chewing action than dry, kibble diets, and has been linked experimentally and clinically to the development of periodontal disease in felines. Experimentally, reduced plaque development has been shown when dry diets, or diets that contain intact animal tissues (e.g., tendons, bones, and intact cow trachea) were fed (Watson, 1994). However, when Clarke and Cameron (1998) examined dental calculus and periodontal disease, they reported no difference between domestic cats fed commercial diets and feral cats consuming whole prey diets, indicating that periodontal disease is not due only to dietary type.

Diet composition

As expected, EXT and CAN met all macro- and micro-nutrient recommendations for domestic cats (AAFCO, 2012). Commercial extruded and canned diets have complex diet formulations, including vitamin and mineral premixes that make them nutritionally complete. They are convenient and consistent products with the assurance of quality and nutritional adequacy provided on the label. These guarantees are supported by independent compositional analysis recently completed on over 1,000 commercial foods (Hill et al., 2009; Streiff et al., 2002) and very few pet food recalls due to nutritional inadequacy.

The GRO and WHO tested herein met the macronutrient recommendations for adult domestic cats (AAFCO, 2012), but were deficient in some minerals. No signs of deficiency were noted for the cats in this study; however, cats were exposed to these diets for only 21 days. Deficient mineral concentrations have been reported previously, with low Cu, Mn, and K concentrations reported in whole prey species, including mice, rats, and quail (Dierenfeld et al., 2002; Clum et al., 1996; 1997) and in homemade diets (Streiff et al., 2002). Prey species, however, are not all reported to be below AAFCO recommendations. The mineral composition

of whole prey may be dependent on diet (Clum et al., 1997), and may partly explain the differences noted between studies. Long-term exposure to nutritionally-deficient diets would have negative impacts on health, including reproduction, bone health, and electrolyte balance. Therefore, feeding nutritionally complete diets is an important responsibility of the zoo or pet owner. These data highlight the importance of obtaining nutrient profiles of whole prey items prior to their long-term feeding. When nutrient deficiencies are identified, alterations in the feeding protocols or supplementation are necessary.

It should also be noted that the NRC and AAFCO recommendations for domestic cats are based on bioavailability of nutrients common in commercial diets. Because the bioavailability of minerals in whole prey and homemade diets may differ significantly, research in this area is needed.

Microbial Contamination

The greatest risk of disease for humans and pets comes from direct contact with raw animal products themselves. There is also a large risk for humans that handle the pet, bowls, and other surfaces that come into contact with raw animal products. Few studies have examined human illness derived from pets (Morse et al., 1976; Sato et al., 2000); however, the presence of bacterial pathogens in raw diets has been well documented (Joffe and Schlesinger, 2002; Weese and Arryo, 2005; Harrison et al., 2006; Strohmeyer et al., 2006). Because of the increased health risks posed by bringing raw animal products into the home, the FDA does not support the use of raw animal diets for feeding domestic pets (CVM, 2004). If raw animal products are fed, care should be taken during handling of the diet and pet, including frequent hand-washing and resisting the urge to kiss your pet. In particular, care should be taken to reduce exposure to at-risk populations, including young children, elderly, immune-compromised persons, and pregnant

women. It should be noted that feeding canned and extruded diets does not completely eliminate risk of pathogenic bacteria exposure from interactions with pets, but these diets are, for all practical purposes, sterile before they leave the container.

Raw animal products may be a source of potentially pathogenic microorganisms, including *Salmonella, Campylobacter* spp., and pathogenic strains of *E. coli,* to the animal or its handler/owner. Poultry species may harbor pathogenic bacteria without any outward signs of disease (White et al., 1997), and ingestion of contaminated foods causes transmission of these pathogenic bacteria to the animals ingesting them (Crump et al., 2002). Whole prey diets containing gut contents make it inevitable that pets will be exposed to foreign bacteria. The sample of WHO fed herein tested positive for *E. coli* and *Salmonella* species. Contamination of poultry species with potentially pathogenic bacteria may occur pre-harvest (e.g., breeding, growth, etc.), during harvest (handling and transport), or after harvest (during slaughter, storage, or transport). Dirty skin, feathers, and gut contents are considered to be the most significant contributors to bacterial contamination. Common practices during slaughter attempt to reduce these risks; however, for whole prey, skin and viscera remain intact. Because these tissues remain, extra caution should be taken pre-harvest to reduce contact of whole prey with pathogenic bacteria.

Although pathogenic bacteria should be avoided in felines, the risk for humans is an even greater concern. Their natural history, digestive physiology (e.g., rapid transit time), and commensal microbiota may allow healthy adult felines to tolerate exposure and harbor pathogenic bacteria without overt symptoms of disease. It is estimated that 1 to 18% of domestic cats may be in a state of asymptotic salmonellosis (Stiver et al., 2003), and the number of reported cases of food-borne illness in pets is believed to be underreported (CVM, 2004). Fecal

samples in this study were not tested for bacterial contamination. Despite the presence of pathogens in the GRO and WHO, animals exhibited no signs of gastrointestinal distress due to any of the dietary treatments tested.

Apparent Total Tract Macronutrient Digestibility and ME

Although apparent total tract macronutrient digestibility values were similar between species, differences due to diet were observed. Differences may have been due to several factors, including ingredient composition, macronutrient composition, or processing procedures. More statistical differences were identified in DOM compared to AWC, which was likely due to a larger sample size used in DOM (n=11 vs. n=4).

Of the few studies in the literature pertaining to raw diets, evidence for increased digestibility of raw vs. extruded diets exists in sand cats (Crissey et al., 1997) and African wildcats (Vester et. al., 2010b). Kerr (2010) also reported higher ($P < 0.05$) apparent total tract DM, CP, and fat digestibilities of a raw beef-based diet (87%, 93%, and 96%, respectively) as compared to a dry chicken-based diet (78%, 82%, and 91%, respectively). Apparent total tract macronutrient digestibilities by cats fed GRO in this study were the highest and within the ranges reported previously (Chapters 3 and 4; Kerr, 2010; Vester et. al., 2008; 2010a; 2010b). The CAN and EXT had intermediate macronutrient digestibilities compared to other published data for raw and extruded diets, while the WHO was more similar to data reported for extruded diets.

Few studies have examined the digestibility of whole prey items by captive exotic felids (Golley et al., 1965; Bennett et al., 2010; Depauw et al., 2012). The authors are aware of only a few studies that have reported digestibility data for ground whole prey in domestic cats (Fekete et al., 2001; 2004). Davidson et al. (1978) compared apparent total tract digestibility in fishers fed deer meat, whole hare, whole quail, or a small whole mammal mix (73% vole, 16% shrew,

11% mouse). Apparent total tract GE digestibility was higher for fishers fed deer (93%), quail (91%) and hare (91%), as compared to those fed the small mammal diet (81%). The proportionately higher skin, fur, and bone content of the small mammal diet may have reduced the GE digestibility. High ash content of whole prey (8 to 15%) also may contribute to poor digestibility of whole prey diets. Bedford and Christian (2000) reported that hair accounted for 2 to 7% units of GE digestibility in pythons fed mice. A similar effect of skin and feathers for WHO vs. GRO may partially explain the lower digestibility of WHO. Grinding also may have increased digestibility of GRO. The apparent total tract DM, CP, and fat digestibility data for domestic cats reported for ground, heat-treated rats (81%, 85%, and 99%, respectively) were slightly lower compared to the GRO fed herein, while data for ground chicken carcass (85%, 94%, and 99%, respectively) were similar (Fekete et al., 2001; 2004).

Differences between dietary DE and estimated ME are reflective of the differences in dietary composition and digestibility. The DE and estimated ME of CAN, EXT, and GRO were similar between studies, while the DE and estimated ME of WHO reflect the differences in dietary CP and fat between studies conducted herein. Metabolizable energy was estimated from the dietary nutrient composition and energy digestibility using predictive equations (NRC, 2006). Because interactions among nutrients and effects of processing are not considered in such calculations, they are limited. Precision may be limited because the predictive equations were developed for traditional canned and extruded diets. The bioavailability of energy in whole prey diets to which the equation is applied may differ from the diets used to obtain the equation. ME intake of AWC was within the range recommended for exotic cats (55 to 260 kcal/d / kg $BW^{0.75}$), while for DOM fed CAN, the ME intake was similar to the recommendation for domestic cats [100 kcal/d/kg $BW^{0.67}$ (NRC, 2006)], but lower for domestic cats fed GRO, EXT, or WHO.

Multiple factors may impact the differences observed between DOM and AWC, including physical activity levels, metabolic differences, and differences in housing.

Nitrogen Balance

Despite differences in N intake and digestibility, the diets fed herein all maintained positive N balance in the domestic cats. Although calculated retained N was positive, cats maintained BW. This phenomenon is common in domestic cat N balance studies that examine high-protein diets and is likely due to N that is unaccounted for because of experimental limitations rather than a truly positive N balance. A majority of N was excreted in the urine (81 to 93%) and is reflective of the high CP digestibility of the diets tested. N balance data herein were similar to those in the literature for extruded and raw meat diets (Chapter 3; Kerr, 2010; Vester et al., 2010b) and purified diets (Green et al., 2008) fed to DOM and AWC.

Blood Metabolites

Diagnostically, it is important to understand how feeding whole prey diets may impact serum chemistry. Given the paucity of data on blood metabolites reported in whole prey, however, it is unclear how the ingredient and macronutrient composition differences between whole prey diets and traditional diets impact the serum chemistry profile.

Elevated serum creatinine concentrations can be diagnostically indicative of kidney dysfunction; however, because serum urea N concentrations were within the normal range for adult cats, it is unlikely that the cats herein were suffering from decreased renal function. Increased serum creatinine may be due to multiple factors, including high dietary intake of creatinine, creatine, or protein (specifically, arginine and glycine), and changes in muscle mass. The differences in serum creatinine due to diet was small and likely insignificant biologically.

The high serum cholesterol concentrations observed for cats fed WHO is of interest. High dietary cholesterol intakes may result in increased serum cholesterol concentrations, and it has long been known that animal products are high in cholesterol. The serum cholesterol data reported herein were similar to those reported for mountain lions and European wildcats in the wild (Murphy et al., 1994; Marco et al., 2000). Research is needed to determine if the greater serum cholesterol observed in cats fed whole prey diets is normal, and what effects it may have on the distribution of lipoprotein fractions. Further research is warranted to determine if separate reference ranges may be necessary for animals fed whole prey diets and what the long-term health effects of these differences may be.

Conclusions

Feeding nutritionally complete diets is an important responsibility of any zoo staff or pet owner. Data are needed to allow for educated decisions regarding whole prey feeding. The commercial canned and extruded diets fed in these studies met the macro- and micro-nutrient recommendations for domestic cats, while the whole prey diets were deficient in some minerals. In addition to mineral deficiencies, raw animal products may be a source of potentially pathogenic microorganisms, and was true of the diets fed herein. The mineral composition of whole prey may be dependent on the diet they are fed, and feeding strategies used to raise whole prey may need to be altered to optimize nutrient composition for the intended consumer.

Whole prey items should only be included as part of a properly balanced diet. If properly balanced, whole prey diets appear to be adequate for maintaining health in the short-term. Whole prey chicks had a lower digestibility than the traditional canned and extruded diets fed herein, while ground whole chicken had a greater digestibility. However, whole prey chick diets had similar apparent total tract macronutrient digestibility to that previously reported for

traditional canned and extruded diets. All diets maintained BW and N balance, and resulted in few differences in blood metabolites. However, long-term studies performed in cats fed whole prey diets are needed. Moreover, future research should increase the number of cat species and prey species examined.

TABLES

Table 5.1 Ingredient composition of a canned diet (CAN), an extruded diet (EXT), ground whole chicken (GRO), and whole chicks (WHO) fed to African wildcats and domestic cats

Treatment	Ingredient composition
CAN (Zupreem®; Premium Nutritional Products, Inc., Shawnee, KS)	Chicken, liver, meat by-products, poultry by-product meal, chicken fat, water, ground corn, powdered cellulose, iodized salt, potassium chloride, taurine, iron oxide, ferrous sulfate, zinc oxide, choline chloride, copper proteinate, manganese sulfate, potassium iodide, sodium selenite, vitamin A supplement, vitamin D3 supplement, vitamin E supplement, thiamine mononitrate, niacin, calcium pantothenate.
EXT (Iams® ProActive Health™ Adult Original with Chicken, P&G Petcare, Cincinnati, OH)	Chicken, chicken by-product meal, corn meal, corn grits, dried beet pulp, poultry by-product meal, natural flavor, dried egg product, brewers dried yeast, sodium bisulfate, potassium chloride, fructooligosaccharides, animal fat (preserved with mixed tocopherols, a source of vitamin E), fish oil (preserved with mixed tocopherols, a source of vitamin E), DL-methionine, choline chloride, calcium carbonate, vitamins (vitamin E supplement, niacin, ascorbic acid, vitamin A acetate, calcium pantothenate, biotin, thiamine mononitrate (source of vitamin B1), pyridoxine hydrochloride (source of vitamin B6), vitamin B12 supplement, riboflavin supplement (source of vitamin B2), inositol, vitamin D3 supplement, folic acid), taurine, minerals (zinc oxide, manganese sulfate, copper sulfate, potassium iodide, cobalt carbonate), rosemary extract.
GRO (Course Ground Michigan Chickens, My Pet Carnivore, Indianapolis, IN)	Meat, bones, and organs, including head and feet, but excluding feathers.
WHO (Rodent Pro, Inglefield, IN)	One to three day-old whole chicks.

Table 5.2 Chemical composition of a canned diet (CAN), an extruded diet (EXT), ground chicken (GRO), or whole chicks (WHO) fed to African wildcats

	Dietary treatment			
Item	CAN	EXT	GRO	WHO
Dry matter (DM), %	40.4	91.8	30.5	23.8
Organic matter, % DM	91.0	92.8	88.1	91.5
Crude protein, % DM	46.5	36.0	47.1	75.6
Acid hydrolyzed fat, % DM	35.6	16.4	36.9	16.3
Gross energy, kcal/g DM	6.37	5.18	6.18	5.50
Ca, % DM	2.50	1.32	3.78	1.95
P, % DM	1.66	1.20	1.93	1.24
Ca : P ratio	1.51	1.10	1.96	1.57
K, % DM	0.69	0.92	0.25	0.84
Na, % DM	0.39	0.58	0.17	0.92
Mg, % DM	0.09	0.11	0.09	0.09
Fe, mg/kg DM	873	181	81	142
Cu, mg/kg DM	10	26	2	4
Mn, mg/kg DM	9	84	2	2
Zn, mg/kg DM	178	321	76	85
S, % DM	0.50	0.73	0.46	1.19

Table 5.3 Chemical composition of a canned diet (CAN), an extruded diet (EXT), ground whole chicken (GRO), or whole chicks (WHO) fed to domestic cats

	Dietary treatment			
Item	CAN	EXT	GRO	WHO
Dry matter (DM), %	37.8	93.6	26.8	22.5
Organic matter, % DM	90.7	93.2	88.4	90.9
Crude protein, % DM	45.7	35.5	54.4	71.7
Acid hydrolyzed fat, % DM	37.8	16.6	37.1	20.3
Gross energy, kcal/g DM	6.3	5.2	6.2	5.9

Table 5.4 Microbial evaluation of a canned diet (CAN), an extruded diet (EXT), ground whole chicken (GRO), or whole chicks (WHO) fed to African wildcats

	Dietary treatment			
Item	CAN	EXT	GRO	WHO
Aerobic plate count, million CFU[1]/g DM[2]	n.d.[3]	n.d.	1.1	2.4
Escherichia coli, CFU/g DM	n.d.	n.d.	n.d.	> 2000
Total coliforms, CFU/g DM	n.d.	n.d.	n.d.	> 2000
Salmonella[4]	Negative	Negative	Negative	Positive
Staphylococcus aureus, CFU/g DM	n.d.	n.d.	n.d.	n.d.
Yeast, CFU/g DM	n.d.	n.d.	n.d.	n.d.
Mold count, CFU/g DM	n.d.	n.d.	1940	n.d.

[1] CFU = colony forming units
[2] DM = dry matter
[3] n.d. = none detected
[4] Negative = < 1 organism / g DM; Positive = ≥ 1 organism / g DM

Table 5.5 Food intake, fecal output, apparent total tract energy and macronutrient digestibility, and estimated ME of African wildcats fed a canned diet (CAN), an extruded diet (EXT), ground whole chicken (GRO), or whole chicks (WHO)

	Dietary treatment					
Item	CAN	EXT	GRO	WHO	SEM	P-value
Intake, g/d as-is	119.0[a]	79.5[a]	195.4[b]	310.0[c]	15.19	<0.001
Intake, g/d dry matter (DM)	47.5[a]	73.0[b]	59.5[ab]	73.8[b]	6.05	0.004
Fecal output, g/das-is	19.3[ab]	34.4[c]	14.3[a]	31.1[bc]	3.77	0.003
Fecal output, g/d DM	8.7	12.7	9.4	13.7	1.80	0.034
Digestibility						
DM, %	80.9	82.7	84.8	81.5	2.53	0.686
Organic matter, %	87.3[a]	85.7[a]	93.6[b]	85.1[a]	1.53	0.008
Crude protein, %	85.7[ab]	80.5[a]	91.3[b]	86.1[ab]	1.77	0.003
Acid hydrolyzed fat, %	94.5[bc]	93.4[b]	97.6[c]	82.2[a]	0.87	<0.001
Gross energy, %	88.8[a]	86.1[a]	94.6[b]	83.4[a]	1.34	0.002
Digestible energy, kcal/g DM	5.7[b]	4.5[a]	5.9[b]	4.6[a]	0.08	<0.001
Metabolizable energy (ME), kcal/g DM[1]	5.3[b]	4.2[a]	5.5[b]	4.0[a]	0.08	<0.001
ME intake (kcal/d)	251.9	304.8	295.5	327.4	30.52	0.196
ME intake (kcal/d/kg $BW^{0.75}$)	91.5	112.4	120.5	109.1	9.59	0.200

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

[1] Metabolizable energy = digestible energy – (0.77 x crude protein).

Table 5.6 Food intake, fecal output, apparent total tract energy and macronutrient digestibility, and estimated ME of domestic cats fed a canned diet (CAN), an extruded diet (EXT), ground whole chicken (GRO), or whole chicks (WHO)

	Dietary treatment					
Item	CAN	EXT	GRO	WHO	SEM	P- value
Intake, g/d as-is	139.5[b]	58.1[a]	143.6[b]	181.2[c]	7.55	<0.001
Intake, g/d dry matter (DM)	52.9[c]	54.5[c]	38.7[a]	40.7[b]	2.03	<0.001
Intake, dietary water mL/d	86.6[b]	3.6[a]	104.8[c]	140.6[d]	5.07	<0.001
Fecal output, g/das-is	29.2[b]	26.4[b]	11.9[a]	19.4[a]	2.95	<0.001
Fecal output, g/d DM	11.6[c]	8.5[b]	6.0[a]	8.5[b]	0.71	<0.001
Digestibility						
DM, %	78.3[a]	84.5[b]	84.5[b]	79.3[a]	0.79	<0.001
Organic matter, %	86.0[b]	87.8[b]	94.1[c]	83.3[a]	0.49	<0.001
Crude protein, %	84.1[a]	85.8[a]	94.3[b]	85.2[a]	0.55	<0.001
Acid hydrolyzed fat, %	96.0[c]	94.1[b]	97.1[c]	84.1[a]	0.38	<0.001
Gross energy, %	88.2[b]	88.0[b]	95.0[c]	83.0[a]	0.46	<0.001
Digestible energy, kcal/g DM	5.6[c]	4.5[a]	5.9[d]	4.9[b]	0.03	<0.001
Metabolizable energy (ME), kcal/g DM[1]	5.2[b]	4.3[a]	5.5[c]	4.4[a]	0.03	<0.001
ME intake (kcal / d)	276.3[c]	232.4[b]	212.5[b]	177.7[a]	12.56	<0.001
ME intake (kcal/ d / kg $BW^{0.75}$)	99.6[c]	83.1[b]	78.3[b]	64.8[a]	8.10	<0.001

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

[1] Metabolizable energy = digestible energy – (0.77 x crude protein).

Table 5.7. Nitrogen (N) metabolism of domestic cats fed a canned diet (CAN), an extruded diet (EXT), ground whole chicken (GRO), or whole chicks (WHO)

	Dietary treatment					
Item	CAN	EXT	GRO	WHO	SEM	P - value
N intake, g/d	3.9[b]	3.1[a]	3.4[a]	4.7[c]	0.28	0.232
Fecal N, g/d	0.6[c]	0.4[b]	0.2[a]	0.7[c]	0.05	<0.001
Urinary N, g/d	2.7[b]	2.2[a]	2.6[b]	3.6[c]	0.14	<0.001
Total N output, g/d	3.3[b]	2.6[a]	2.8[a]	4.3[c]	0.17	<0.001
Absorbed N, g/d	3.3[b]	2.7[a]	3.2[b]	4.0[c]	0.19	<0.001
Retained N, g/d	0.5	0.5	0.6	0.4	0.15	0.104

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

Table 5.8 Serum chemistry of domestic cats fed a canned diet (CAN), an extruded diet (EXT), ground whole chicken (GRO), or whole chicks (WHO)

Item	Dietary treatment				SEM	P - value	Reference range
	CAN	EXT	GRO	WHO			
Creatinine, mg/dL	1.91[a]	1.98[ab]	2.10[b]	1.96[a]	0.09	0.011	0.4 to 1.6
Urea nitrogen, mg/dL	28.5[b]	25.8[a]	30.8[b]	33.6[c]	2.25	<0.001	18 to 38
Total protein, g/dL	7.3[ab]	7.0[a]	7.2[ab]	7.4[b]	0.13	0.006	5.8 to 8.0
Albumin, g/dL	3.50[b]	3.32[a]	3.49[b]	3.38[ab]	0.04	0.001	2.8 to 4.1
Calcium, mg/dL	9.6	9.7	9.6	9.7	0.14	0.595	8.8 to 10.2
Phosphorus, mg/dL	4.0[ab]	4.2[b]	3.8[a]	4.2[b]	0.14	0.010	3.2 to 5.3
Sodium, mmol/L	149.7[ab]	149.3[a]	151.1[b]	150.5[ab]	0.59	0.007	145 to 157
Potassium, mmol/L	4.5	4.6	4.5	4.5	0.11	0.672	3.6 to 5.3
Chloride, mmol/L	117.4	117.3	117.6	118.0	0.47	0.528	109 to 126
Glucose, mg/dl	93.7[ab]	93.9[b]	86.6[ab]	81.5[a]	10.16	0.027	60 to 122
ALP[1], U/L	25.3[b]	17.8[a]	21.5[ab]	17.1[a]	2.41	0.001	10 to 85
ALT[2], U/L	43.7[a]	59.6[b]	41.6[a]	46.1[ab]	4.62	0.011	14 to 71
Cholesterol, mg/dL	201.5[a]	178.4[a]	177.7[a]	314.3[b]	14.73	<0.001	66 to 170
NEFA[3], mEq/L	0.64[b]	0.43[a]	0.66[b]	0.61[ab]	0.08	0.008	NA[4]
Triglycerides, mg/dL	28.5[ab]	26.4[a]	34.8[c]	32.8[bc]	1.91	<0.001	21 to 166

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

[1] ALP = alkaline phosphatase.

[2] ALT = alanine aminotransferase.

[3] NEFA = non-esterified fatty acids.

[4] NA = none available.

CHAPTER 6: CHEMICAL ANALYSES OF COMMERCIAL WHOLE PREY ITEMS TARGETED FOR CONSUMPTION BY ZOO AND DOMESTIC PET FELIDS

ABSTRACT

Whole prey diets are popular in the zoo and home setting for captive exotic and domestic felids, respectively. In addition to providing nutrients, whole prey diets encourage species typical behaviors. Data on whole prey has primarily focused on non-nutritive benefits. Our objective was to evaluate 20 whole prey sources: mice (1 to 2 d, 10 to 13 d, 21 to 25 d, 30 to 40 d, and 150 to 180 d of age); rats (1 to 4 d, 10 to 13 d, 21 to 25 d, 33 to 42 d, and > 60 d of age); rabbits (still born, 30 to 45 d, > 65 d with skin, and >65 d of age with skin removed); chicken (1 to 3 d of age, ground adult); duck (ground adult); and quail (1 to 3 d, 21 to 40 d, and > 60 d of age). Macronutrient concentrations exceeded the requirements of the domestic cat (15 to 40% DM, 34 to 75% CP, 10 to 60%, and 8 to 18% ash; AAFCO, 2012). For a majority of the samples, amino acid concentrations were greater than the recommendations for domestic cats, and amino acid scores were greater than 88 for all species except rabbits. The first limiting amino acids for whole prey were Cys + Met, Met, Tau, and Trp. In the 30 to 45 d-old rabbit, taurine concentration (0.01%) was lower than that recommended for domestic cats (0.10% DM). A majority of whole prey samples had mineral concentrations below AAFCO recommendations (K, Na, Cl, Mg, Cu, Mn, Zn). All of the avian samples had at least one mineral lower than AAFCO recommendations for domestic cats, while 50% of mammalian species had deficiencies. These data highlight the importance of obtaining nutrient profiles of whole prey items prior to long-term feeding. When nutrient deficiencies are identified, alterations in the feeding protocols or supplementation are necessary. Research is needed on the bioavailability of nutrients in whole prey.

INTRODUCTION

In the zoo setting, whole prey often are fed as enrichment with the aim of encouraging species typical behavior, specifically increasing the time and energy spent finding and consuming food (Bond and Lindburg, 1990; Shepardson et al., 1993; Ziegler, 1995). For domestic cats, whole prey diets are one of a number of unconventional diets (e.g., vegetarian, natural, organic, and raw diets) that have recently increased in popularity.

A large portion of data on whole prey are from anecdotal, unpublished, or non-peer reviewed sources (Powers et al., 1989), and primarily focus on non-nutritive benefits. Reported nutrient composition of commonly fed whole prey (i.e., mouse, rat, guinea pig, rabbit, quail, chicken) are variable. Variation in nutrient composition of whole prey can result from differences in diet, genetics, age, sex, or an interaction among these variables (Clum et al., 1997; Dierenfeld et al., 1996; Douglas et al., 1994). Because of the variation, species-specific differences are not readily predictable. Few in-depth examinations of nutrient composition of commonly fed whole prey have been performed (Clum et al., 1997; Davidson et al., 1978; Dierenfeld et al., 1996; Douglas et al., 1994), and with little attention paid to commercially available whole frozen prey. Additionally, few studies have reported apparent total tract digestibility data for whole prey items in small captive exotic felids (Golley et al., 1965) or domestic cats (Fekete et al., 2001; 2004).

Because dietary nutrient composition and bioavailability have implications as it pertains to meeting the needs of felids, it is important to determine the composition, digestibility, and bioavailability of whole prey diets in felids. In addition to proximate analysis, protein quality essential fatty acid, mineral, and vitamin concentrations are of interest. Our objective was to

evaluate macronutrient, amino acid, and mineral composition of 20 whole prey sources for domestic and captive exotic felids.

MATERIALS AND METHODS

Whole Prey

The following whole prey items were analyzed: mice (1 to 2 d, 10 to 13 d, 21 to 25 d, 30 to 40 d, and 150 to 180 d-old); rats (1 to 4 d, 10 to 13 d, 21 to 25 d, 33 to 42 d, and > 60 d-old); rabbits [still born, 30 to 45 d, > 65 d-old (with skin, and with skin removed)]; chicken (1 to 3 d-old); and quail (1 to 3 d, 21 to 40 d, and > 60 d-old). Whole prey items were obtained as whole carcasses [Rodent Pro, Inglefield, IN and My Pet Carnivore, Indianapolis, IN (stillborn rabbits only)]. The > 65 d-old rabbit without skin was obtained as a whole carcass and skinned. Three lots of each whole prey item (Table 6.1; obtained in January, April, and September of 2011) were analyzed, except still born rabbits. Only one lot of 30 stillborn rabbits was available during this time. Additionally, three lots of ground chicken samples and ground duck samples were obtained (454 g/lot; My Pet Carnivore). These ground samples contained meat, bones, and organs, including head and feet, but excluding feathers.

Chemical Analysis

Whole prey items were composited within each lot, then prepared for analyses, and analyzed according to methods described in Chapter 3 for dietary treatments. Whole prey items from all lots were analyzed for dry matter (DM), organic matter (OM), crude protein (CP), acid hydrolyzed fat, total dietary fiber (TDF), and gross energy (GE). In addition, diet samples from lot 1 were analyzed for amino acid (AA) concentrations, and for mineral concentrations as described in Chapter 5.

RESULTS

Mouse

Data for proximate, mineral, and AA composition of mice are presented in Table 6.2, Table 6.3, and Table 6.4, respectively. Dry matter concentration was 20% in 1 to 2 d-old mice, and 27 to 28% for all other ages. Except for CP and fat concentrations in 10 to 13 d-old mice (51% and 41%, respectively), OM, CP, acid hydrolyzed fat, and TDF were similar for all ages of mice (87 to 90%, 60 to 62%, 25 to 29%, and 0.5 to 4% DM, respectively). Mineral concentrations were greater than AAFCO recommendations for 21 to 25 d-old, 30 to 40 d-old, and 150 to 180 d-old mice. In 1 to 2 d-old mice, however, the Ca:P ratio (0.88) was lower than common practice (1:1 to 2:1) for cats. Mn concentration was lower than that recommended (7.5 mg/kg DM; AAFCO, 2012) for cats in 1 to 2 d-old and 10 to 13 d-old mice (2 and 3 mg/kg DM, respectively). The 10 to 13 d-old mice also had lower Mg concentrations (0.07 % DM; AAFCO, 2012) than that recommended for growth and reproduction by AAFCO (0.08 % DM), and lower Zn concentrations (58 mg/kg DM) than that recommended for all life stages by AAFCO (75 mg/kg DM). All AA were present in concentrations greater than that required by AAFCO and AAS values were high (90 to 104).

Rats

Data for proximate, mineral, and AA composition of rats are presented in Table 6.5, Table 6.6, and Table 6.7, respectively. Dry matter concentrations increased from 16 to 33% with age. Organic matter and TDF concentrations were similar for all ages of rats (88 to 89% and 0.9 to 4% DM, respectively). Crude protein concentrations were highest in 1 to 4 d-old rats (69% DM), intermediate in 10 to 13 d-old and 21 to 25 d-old rats (63% DM), and lowest in 32 to 42 d-old and > 60 d-old rats (58% DM). Acid hydrolyzed fat concentrations were highest in 10 to 13

d-old and > 60 d-old rats (31 and 29% DM, respectively), intermediate in 21 to 25 d-old and 32 to 42 d-old rats (26 to 27% DM), and lowest in 1 to 4 d-old rats (19% DM). In 1 to 4 d-old rats, the Ca:P ratio (0.98) was slightly lower than common practice (1:1 to 2:1) for cats. Mn concentration was lower than that recommended by AAFCO (7.5 mg/kg) for 1 to 4 d-old and 10 to 13 d-old rats (2 mg/kg DM). The 10 to 13 d-old and > 60 d-old rats also had lower Zn concentrations (70 and 57 mg/kg DM, respectively) than that recommended for all life stages by AAFCO (75 mg/kg). All AAs were present in concentrations greater than required by AAFCO and AAS values were high (95 to 105).

Rabbits

Data for proximate, mineral, and AA composition of rabbits are presented in Table 6.8, Table 6.9, and Table 6.10, respectively. Dry matter concentrations increased from 20 to 31% with age. Organic matter concentrations were similar for all ages of rabbits (85 to 87% DM). Crude protein and acid hydrolyzed fat concentrations ranged from 57 to 63% DM and from 16 to 26% DM, respectively. Variation in CP and fat were high, potentially because there were few animals per lot. Mn concentration was lower than that recommended by AAFCO (7.5 mg/kg DM) for stillborn rabbit (3 mg/kg DM). The intact rabbit had lower Cl and Zn concentrations (0.29% and 72 mg/kg DM, respectively) than that recommended by AAFCO (0.3 % and 75 mg/kg DM). All AAs except taurine were present in concentrations greater than that required by AAFCO for all life stages. Taurine was lower than that recommended by AAFCO (0.10%) for 30 to 45 d-old rabbits (0.01% DM) and borderline for >65 d-old rabbits (0.10% DM). The AAS for stillborn rabbits was 81, with the LAA being methionine, while the 30 to 45 d-old, and > 65 d-old intact and skinned rabbits were limited by taurine and had lower AAS (6, 56 and 57, respectively).

Skinned and intact rabbits (> 65 d-old) were similar in macronutrient and AA composition. Although the Ca:P ratio was similar, the Ca and P concentrations were higher in skinned than intact rabbits (4.0 vs. 2.3% DM and 1.4 vs. 2.3% DM, respectively).

Quail

Data for proximate, mineral, and AA composition of quail are presented in Table 6.11, Table 6.12, and Table 6.13, respectively. Dry matter concentrations increased from 23 to 30% with age. Organic matter concentrations were similar for all ages of quail (86 to 90% DM). Crude protein concentration was lowest in 1 to 3 d-old quail (66% DM), intermediate in > 60 d-old quail (70% DM), and highest in 21 to 40 d-old quail (75% DM). Fat concentration was highest in 1 to 3 d-old quail (26% DM), intermediate in > 60 d-old quail (19% DM), and lowest in 21 to 40 d-old quail (13% DM). For all ages of quail, Mn concentrations (2 to 3 mg/kg DM) were lower than those recommended for all life stages by AAFCO (7.5 mg/kg), and Mg concentrations (0.05 to 0.07 % DM) were lower than those recommended for growth and reproduction by AAFCO (0.08% DM). K, Cl, and Zn concentrations in the 1 to 3 d-old quail (0.40%, 0.16%, and 57 mg/kg DM, respectively) and 21 to 40 d-old quail (0.35% DM, 0.11% DM, and 50 mg/kg DM, respectively) were lower than those recommended by AAFCO (0.6% DM, 0.3% DM, and 75 mg/kg DM, respectively). The 1 to 3 d-old quail also had lower Cu concentration (4 mg/kg DM) than that recommended by AAFCO (5 mg/kg DM), and the 21 to 40 d-old quail also had lower Na concentration (0.15% DM) than that recommended by AAFCO (0.2% DM). All AAs were present in concentrations greater than that required by AAFCO and AAS values were high (97 to 107).

Chicken

Data for proximate, mineral, and AA composition of chicken and duck are presented in Table 6.14, Table 6.15, and Table 6.16, respectively. Concentrations of DM and fat were higher and CP concentration lower in the ground chicken sample (28%, 34%, and 54% DM, respectively) compared to the 1 to 3 d-old chicks (23%, 20%, and 72% DM, respectively). Cu, Mn, and Zn concentrations in 1 to 3 d-old chicks and ground chicken (4 mg/kg, 2 to 3 mg/kg, and 57 to 59 mg/kg DM, respectively) were lower than that recommended for all life stages by AAFCO (5 mg/kg, 7.5 mg/kg, and 75 mg/kg DM, respectively), and Mg concentrations (0.07% DM) were lower than those recommended for growth and reproduction by AAFCO (0.08% DM). All AAs were present in concentrations greater than that required by AAFCO and AAS values were high (88 to 104).

Duck

Ground duck had higher DM and fat concentrations (37% and 51% DM) and lower CP concentration (40% DM) compared to other whole prey items. K, Na, Cl, Mn, and Zn concentrations in the ground duck (0.35%, 0.15%, 0.11%, 2 mg/kg, and 50 mg/kg DM, respectively) were lower than those recommended for all life stages by AAFCO (0.6%, 0.2%, 0.3%, 7.5 mg/kg, and 75 mg/kg DM, respectively), and Mg concentration (0.05 mg/kg DM) was lower than that recommended for growth and reproduction by AAFCO (0.08 mg/kg DM). The combined concentration of methionine + cysteine (1.09 % DM) was the LAA (AAS: 93) and was lower than that recommended by AAFCO (1.10%).

DISCUSSION

Small felines consume predominantly animal prey. The cat has unique digestive and metabolic adaptations believed to be due to the evolutionary impact of consuming a prey diet,

including a high dietary protein requirement (Green et al., 2008), inability to synthesize arginine *de novo*, and low endogenous synthesis of taurine (Pion et al., 1987; 1989). Data are lacking regarding the nutrient composition of the natural or ancestral diets of small cats; however, estimations have been made for the diet of contemporary feral cats utilizing both dietary habits and compositional data from the literature (Plantinga et al., 2011). Plantinga et al. (2011) reviewed 27 articles and reported that feral cats consumed mammals (78%), birds (16%), reptiles/amphibians (3.7%), invertebrates (1.2%), and fish (0.3%), with minimal intake of plant material. The estimated nutrient composition (DM basis) of this diet was 88% OM, 62.7% CP, and 28% fat. Macronutrient concentrations for the wild whole prey reported by Plantinga et al. (2011) had smaller nutrient ranges (24 to 35% DM, 55 to 69% CP, 9 to 31% fat, and 9 to 15% ash) than the data presented herein (15 to 40% DM, 34 to 75% CP, 10 to 60% fat, and 8 to 18% ash). Differences between the data reported herein and summarized that for wild samples may be due to the paucity of literature for wild whole prey. For example, during the active growth period, the fat percentage of animals generally increases, while the water percentage decreases (Spray and Widowson, 1950). The data examined for wild prey contained only juveniles and adult animals (Plantinga et al., 2011), while the lowest DM concentrations observed were in 1 to 2 d-old mice and 1 to 4 d-old rats. Additionally, the high energy density of diets and lower energy expenditure of animals raised in the laboratory or farm setting may partially explain the higher fat concentrations reported herein compared to wild prey. Fat concentrations greater than 35% have been reported previously for feeder prey (Douglas et al., 1994; Clum et al., 1996). While high fat concentrations also have been reported for small mammals pre-hibernation (e.g., 41% as-is basis for ground squirrels; Buck and Barnes, 1999), wild felines would not be exposed to elevated fat concentrations on a consistent basis. Additionally, fat digestibility can be high

(96 to 99%) for whole prey species, and should be considered if caloric density is a concern. Overall, whole prey species reported herein exceeded the macronutrient requirements of the domestic cat (AAFCO, 2012).

For a majority of the samples, AA concentrations were greater than the AAFCO recommendations for domestic cats, and AAS values were greater than 88 for all species except rabbits. The LAA for whole prey were Cys + Met, Met, Tau, and Trp. Taurine was lower than that recommended by AAFCO for the 30 to 45 d-old rabbit, and borderline for intact and skinned rabbits > 65 d-old. Dilated cardiomyopathy and retinopathies associated with low plasma Tau have been reported in captive exotic cats and domestic cats (Burton et al., 1988; Markwell and Earle, 1995; Ofri et al., 1996; Pion et al., 1987). Deficiency of Tau during pregnancy of queens results in fetal resorption, abortion, stillbirths, and low birth weights (Sturman et al, 1986). Glasgow et al. (2002) reported dilated cardiomyopathy due to Tau deficiency in a domestic cat fed a ground whole rabbit diet (Tau = 0.13% DM) and heart muscle changes consistent with Tau deficiency in 70% of the remaining cats on the whole rabbit treatment. The Tau concentration of whole rabbits reported herein (≤ 0.10%) was similar to that reported by Glasgow. When fed whole rabbits (Tau = 0.6% DM; i.e., higher than recommendations for domestic cats) for 26 d, cheetahs maintained serum Tau levels (Depauw et al., 2012). When feeding whole rabbits, special care should be made to ensure Tau concentrations are greater than recommendations for domestic cats.

A majority of whole prey samples had mineral concentrations below AAFCO recommendations (K, Na, Cl, Mg, Cu, Mn, Zn). In general, the major roles of minerals are as constituents of bone, electrolytes and fluid balance, and co-factors or catalysts for enzymatic

reactions. Mineral imbalances often result in poor growth and reproduction, bone and joint disorders, and renal and urinary tract disorders (NRC, 2006).

All of the avian samples had at least one mineral lower than recommendations for domestic cats, while 50% of mammalian species had deficiencies. This may be due to the prevalence of feeding carnivorous birds and snakes with mammalian species. Although compositional evaluations of whole avian prey exist, more data are available for rodent species.

Similar mineral deficiencies have been reported previously (low Cu, Mn, and K concentrations) in whole prey species, including mice, rats, and quail (Chapter 5; Dierenfeld et al., 2002; Clum et al., 1996; 1997). Prey species, however, are not all reported to be below AAFCO recommendations. Although it is likely that multiple factors impact nutrient composition (e.g., life stage, strain, sex), one factor that can be controlled is diet (Clum et al., 1997). Given the deficiencies that have been noted in whole prey, it is unclear if whole prey that consistently meet the nutrient requirements of domestic cats can be produced for all species and ages. Research is needed to determine the optimum diet for prey of each species and age. Regardless of class, all of the young animals (1 to 2 d and 10 to 13 d-old mice, 1 to 4 d-old and 10 to 13 d-old rats, stillborn rabbits, and 1 to 3 d-old chicks and quail) had mineral deficiencies compared to recommendations for domestic cats (AAFCO, 2012), which indicates that maternal nutrition also may need to be optimized when keeping the requirements of domestic cats in mind.

Conclusions

These data highlight the importance of obtaining nutrient profiles of whole prey items prior to long-term feeding. When nutrient deficiencies are identified, alterations in the feeding protocols or supplementation are necessary. It should also be noted that the NRC (2006) and AAFCO (2012) recommendations for domestic cats are based on the bioavailability of nutrients

common in commercial diets. Because the bioavailability of minerals in whole prey and homemade diets also may differ significantly, research in this area is needed. Whole prey samples items were each obtained from only one source. Further research is needed to verify the findings herein from multiple sources.

TABLES

Table 6.1 Source specifications for whole prey items obtained for chemical analysis[1]

	Number of Animals			Size	
Item	Lot 1	Lot 2	Lot 3	Length (cm)	Weight (g)
Mouse, *Mus musculus*					
1 to 2 d	400	200	200	1.3 to 2.5	1.9 to 2.4
10 to 13 d	200	100	100	3.2 to 3.8	4.5 to 7.0
21 to 25 d	100	50	50	5.1 to 6.4	13.0 to 19.0
30 to 40 d	50	50	50	6.4 to 7.6	20.0 to 29.0
150 to 180 d	25	25	25	7.6 to 9.5	30.0 to 50.0
Rat, *Rattus norvegicus*					
1 to 2 d	300	100	100	3.8 to 5.1	3.0 to 8.0
10 to 13 d	100	100	100	5.1 to 6.4	9.0 to 19.0
21 to 25 d	25	25	25	8.9 to 11.4	30.0 to 44.0
30 to 40 d	10	10	10	15.2 to 20.3	85.0 to 174.0
150 to 180 d	3	3	3	22.9 to 27.9	275.0 to 374.0
Rabbit, *Oryctolagus cuniculus*					
30 to 45 d	2	2	2		454 to 908
> 65 d	1	1	1		1814 to 2722
> 65 d	1	1	1		1814 to 2722
Chicken, *Gallus gallus*					
1 to 3 d	25	25	25		30 to 35
Quail, *Coturnix coturnix*					
1 to 3 d	100	100	100		7.5 to 10
21 to 40 d	20	10	10		100 to 129
60 d	5	5	5		155 to 189

[1] Obtained from Rodent Pro (Inglefield, IN).

Table 6.2 Macronutrient and energy composition of commercially obtained whole prey mice (presented as mean ± SD)[1]

	Age (d)																				
Item	1 to 2				10 to 13				21 to 25				30 to 40				150 to 180				Mean ± SD
Dry matter (DM), %	19.53	±	0.49		28.00	±	0.51		27.88	±	1.45		27.91	±	0.68		27.47	±	1.12		26.16 ± 3.53
Organic matter, % DM	89.73	±	1.28		90.34	±	1.77		87.14	±	1.83		88.39	±	1.95		88.91	±	0.99		88.90 ± 1.78
Crude protein, % DM	60.83	±	0.50		50.88	±	1.33		62.65	±	3.68		60.48	±	1.70		60.08	±	3.06		58.98 ± 4.73
Acid hydrolyzed fat, % DM	29.37	±	0.84		40.87	±	2.94		25.15	±	2.03		26.05	±	1.87		28.15	±	2.28		29.92 ± 6.14
Total dietary fiber, % DM	1.46	±	0.44		0.49	±	0.73		2.16	±	0.81		3.74	±	0.77		3.39	±	0.79		2.25 ± 1.39
Gross energy, kcal/g DM	6.17	±	0.03		6.81	±	0.14		5.95	±	0.12		6.06	±	0.10		6.21	±	0.26		6.24 ± 0.33

[1] Three lots per age were analyzed.

Table 6.3 Mineral composition of commercially obtained whole prey mice[1]

	Age (d)						
Item	1 to 2	10 to 13	21 to 25	30 to 40	150 to 180	Mean	SD
Ca, % dry matter (DM)	1.29	1.38	2.45	1.99	2.01	1.82	0.48
P, % DM	1.46	1.25	1.76	1.55	1.54	1.52	0.18
Ca:P ratio	0.88	1.10	1.39	1.28	1.30	1.19	0.20
K, % DM	1.16	0.78	0.86	0.84	0.86	0.90	0.15
Na, % DM	0.60	0.32	0.40	0.36	0.42	0.42	0.11
Cl, % DM	0.77	0.43	0.50	0.47	0.55	0.54	0.13
Mg, % DM	0.09	0.07	0.10	0.10	0.11	0.09	0.01
Fe, mg/kg DM	180	101	164	154	198	159	36
Cu, mg/kg DM	15	27	7	10	10	13	7
Mn, mg/kg DM	2	3	12	16	37	14	14
Zn, mg/kg DM	76	58	76	79	104	78	16
S, % DM	0.60	0.52	0.77	0.73	0.74	0.67	0.11

[1] One lot per age was analyzed.

Table 6.4 Amino acid (AA) composition of commercially obtained whole prey mice[1]

	Age (d)						
Item	1 to 2	10 to 13	21 to 25	30 to 40	150 to 180	Mean	SD
AA, % DM	51.13	45.28	60.68	55.42	58.08	54.12	6.07
Total essential AA	24.48	21.22	28.30	25.93	27.22	25.43	2.75
Arginine	3.24	2.98	4.06	3.80	3.93	3.60	0.47
Histidine	1.44	1.15	1.50	1.38	1.50	1.39	0.15
Isoleucine	2.10	1.81	2.37	2.20	2.24	2.14	0.21
Leucine	4.26	3.69	4.81	4.44	4.68	4.38	0.44
Lysine	3.88	3.36	4.48	4.07	4.34	4.03	0.44
Methionine	1.09	0.97	1.31	1.21	1.30	1.18	0.15
Phenylalanine	2.28	2.01	2.62	2.40	2.62	2.39	0.26
Taurine	0.64	0.47	0.81	0.72	0.18	0.56	0.25
Threonine	2.11	1.83	2.52	2.17	2.58	2.24	0.31
Tryptophan	0.46	0.39	0.51	0.46	0.76	0.52	0.14
Valine	2.98	2.57	3.29	3.09	3.10	3.01	0.27
Total non-essential AA	26.65	24.05	32.38	29.49	30.86	28.69	3.34
Alanine	3.04	2.69	3.68	3.40	3.46	3.25	0.39
Aspartate	4.55	3.92	5.25	4.84	5.08	4.73	0.52
Cysteine	0.72	0.94	1.40	1.24	1.34	1.13	0.29
Glutamate	7.18	6.13	7.83	7.30	7.19	7.13	0.62
Glycine	3.65	3.40	4.85	4.56	4.37	4.17	0.62
Hydroxylysine	0.07	0.17	0.19	0.17	0.19	0.16	0.05
Hydroxyproline	0.48	0.53	0.99	0.85	0.94	0.76	0.24
Ornithine	0.20	0.25	0.19	0.13	0.12	0.18	0.05
Proline	2.82	2.58	3.47	3.21	3.33	3.08	0.37
Serine	2.24	1.85	2.45	1.96	2.72	2.24	0.36
Tyrosine	1.72	1.59	2.10	1.84	2.12	1.87	0.23
Amino acid score	96	104	101	100	90		
First limiting amino acid	CYS + MET	MET	TRP	TRP	TAU		

[1] One lot per age was analyzed.

Table 6.5 Macronutrient and energy composition of commercially obtained whole prey rats (presented as mean ± SD)[1]

	Age (d)											
Item	1 to 4		10 to 13		21 to 25		32 to 42		>60d		Mean	± SD
Dry matter (DM), %	15.88	± 0.18	18.21	± 0.47	26.52	± 0.29	27.72	± 0.39	32.75	± 1.00	24.22	± 6.50
Organic matter, % DM	88.17	± 0.30	89.15	± 0.38	87.51	± 1.47	87.94	± 0.44	88.31	± 1.11	88.21	± 0.93
Crude protein, % DM	68.59	± 0.17	63.46	± 5.26	63.21	± 1.78	58.95	± 3.61	58.70	± 2.54	62.58	± 4.61
Acid hydrolyzed fat, % DM	19.29	± 1.00	30.50	± 3.24	26.03	± 2.24	26.74	± 1.31	29.18	± 2.01	26.35	± 4.39
Total dietary fiber, % DM	2.07	± 0.45	0.85	± 1.29	3.12	± 0.93	4.20	± 1.17	1.56	± 1.32	2.36	± 1.53
Gross energy, kcal/g DM	5.73	± 0.13	6.34	± 0.16	6.05	± 0.29	5.99	± 0.08	6.13	± 0.34	6.05	± 0.28

[1] Three lots per age were analyzed.

Table 6.6 Mineral composition of commercially obtained whole prey rats[1]

	Age (d)						
Item	1 to 4	10 to 13	21 to 25	32 to 42	>60	Mean	SD
Ca, % dry matter (DM)	1.62	1.45	2.69	2.25	2.14	2.03	0.50
P, % DM	1.66	1.40	1.92	1.65	1.46	1.62	0.21
Ca:P ratio	0.98	1.04	1.40	1.37	1.47	1.25	0.22
K, % DM	1.19	0.98	0.91	0.84	0.69	0.92	0.18
Na, % DM	0.86	0.58	0.43	0.36	0.29	0.50	0.23
Cl, % DM	1.04	0.71	0.55	0.46	0.33	0.62	0.27
Mg, % DM	0.11	0.09	0.12	0.11	0.10	0.11	0.01
Fe, mg/kg DM	285	162	117	155	123	171.60	68.04
Cu, mg/kg DM	22	22	7	9	7	13.80	8.47
Mn, mg/kg DM	2	2	24	9	11	9.60	9.02
Zn, mg/kg DM	95	70	98	95	57	84.60	17.33
S, % DM	0.63	0.52	0.64	0.55	0.53	0.57	0.06

[1] One lot per age was analyzed.

Table 6.7 Amino acid (AA) composition of commercially obtained whole prey rats[1]

Item	Age (d)					Mean	SD
	1 to 4	10 to 13	21 to 25	32 to 42	> 60		
AA, % DM	62.20	59.66	57.03	54.04	57.42	58.07	3.05
Total essential AA	29.70	28.22	25.28	24.65	25.84	26.74	2.14
Arginine	4.12	4.00	4.02	3.70	3.94	3.96	0.16
Histidine	1.82	1.60	1.37	1.35	1.44	1.52	0.20
Isoleucine	2.39	2.30	2.07	2.08	2.23	2.21	0.14
Leucine	5.14	4.83	4.24	4.12	4.30	4.53	0.44
Lysine	4.84	4.48	3.96	3.94	4.21	4.29	0.38
Methionine	1.26	1.21	1.14	1.17	1.25	1.21	0.05
Phenylalanine	2.77	2.67	2.40	2.33	2.41	2.52	0.19
Taurine	0.61	0.50	0.22	0.24	0.29	0.37	0.17
Threonine	2.81	2.66	2.41	2.20	2.30	2.48	0.25
Tryptophan	0.62	0.82	0.59	0.68	0.50	0.64	0.12
Valine	3.33	3.15	2.84	2.84	2.97	3.03	0.21
Total non-essential AA	32.50	31.44	31.75	29.39	31.58	31.33	1.16
Alanine	3.75	3.55	3.46	3.34	3.58	3.54	0.15
Aspartate	5.45	5.11	4.76	4.60	4.97	4.98	0.33
Cysteine	0.90	0.88	1.27	0.95	1.08	1.02	0.16
Glutamate	8.44	8.00	7.39	6.98	7.55	7.67	0.56
Glycine	4.38	4.31	5.07	4.70	5.13	4.72	0.38
Hydroxylysine	0.19	0.25	0.25	0.21	0.21	0.22	0.03
Hydroxyproline	0.71	0.87	1.30	1.18	1.37	1.09	0.28
Ornithine	0.15	0.16	0.14	0.14	0.11	0.14	0.02
Proline	3.27	3.28	3.48	3.29	3.51	3.37	0.12
Serine	3.09	2.93	2.60	2.17	2.17	2.59	0.42
Tyrosine	2.17	2.09	2.02	1.83	1.90	2.00	0.14
Amino acid score	95	96	97	105	103		
First limiting amino acid	CYS + MET	CYS + MET	MET	MET	TRP		

[1] One lot per age was analyzed.

Table 6.8 Macronutrient and energy composition of commercially obtained whole prey rabbits (presented as mean ± SD)[1]

	Age (d)											
				> 65								
Item	Stillborn	30 to 45		Intact			Skinned			Mean	±	SD
Dry matter (DM), %	20.22	25.66	± 2.21	30.91	±	1.80	30.42	±	2.63	28.12	±	4.08
Organic matter, % DM	88.62	85.19	± 1.06	87.34	±	2.10	84.16	±	1.28	85.87	±	2.07
Crude protein, % DM	57.46	63.96	± 3.39	61.47	±	4.35	57.16	±	4.39	60.52	±	4.48
Acid hydrolyzed fat, % DM	26.36	15.89	± 4.79	23.65	±	4.83	25.15	±	5.55	22.05	±	5.99
Total dietary fiber, % DM	2.74	7.18	± 2.85	3.81	±	0.48	3.49	±	0.68	4.62	±	2.27
Gross energy, kcal/g DM	5.94	5.55	± 0.56	5.96	±	0.10	5.58	±	0.14	5.72	±	0.34

[1] Three lots per age were analyzed, except for stillborn rabbits (n = 1).

Table 6.9 Mineral composition of commercially obtained whole prey rabbits[1]

	Age (d)				Mean	SD
			> 65			
Item	Stillborn	30 to 45	Intact	Skinned		
Ca, % dry matter (DM)	1.98	2.41	2.30	4.06	2.69	0.93
P, % DM	1.57	1.63	1.40	2.29	1.72	0.39
Ca:P ratio	1.26	1.48	1.64	1.77	1.54	0.22
K, % DM	0.87	0.73	0.60	0.73	0.73	0.11
Na, % DM	0.71	0.36	0.26	0.33	0.41	0.20
Cl, % DM	0.71	0.42	0.29	0.40	0.45	0.18
Mg, % DM	0.09	0.12	0.10	0.12	0.11	0.02
Fe, mg/kg DM	464	196	149	193	250.50	143.95
Cu, mg/kg DM	19	29	35	25	27.00	6.73
Mn, mg/kg DM	3	36	16	8	15.75	14.52
Zn, mg/kg DM	107	117	72	84	95.00	20.64
S, % DM	0.54	0.57	0.52	0.43	0.52	0.06

[1] One lot per age was analyzed.

Table 6.10 Amino acid (AA) composition of commercially obtained whole prey rabbits[1]

	Age (d)					
			> 65			
Item	Stillborn	30 to 45	Intact	Skinned	Mean	SD
AA, % DM	53.39	54.50	51.86	53.53	53.32	1.09
Total essential AA	25.31	25.29	23.46	24.49	24.64	0.87
Arginine	3.38	3.76	3.55	3.55	3.56	0.16
Histidine	1.76	1.58	1.35	1.37	1.52	0.19
Isoleucine	1.89	2.15	2.03	2.11	2.05	0.11
Leucine	4.65	4.38	3.98	4.10	4.28	0.30
Lysine	4.19	4.00	3.75	4.14	4.02	0.20
Methionine	0.90	1.13	1.10	1.22	1.09	0.14
Phenylalanine	2.46	2.33	2.11	2.20	2.28	0.15
Taurine	0.29	0.01	0.10	0.10	0.13	0.12
Threonine	2.31	2.36	2.15	2.16	2.25	0.11
Tryptophan	0.43	0.52	0.46	0.65	0.52	0.10
Valine	3.05	3.08	2.87	2.90	2.98	0.11
Total non-essential AA	28.08	29.21	28.40	29.05	28.69	0.53
Alanine	3.41	3.29	3.21	3.52	3.36	0.14
Aspartate	4.64	4.74	4.49	4.66	4.63	0.10
Cysteine	0.93	1.28	1.29	0.59	1.02	0.33
Glutamate	7.14	7.40	7.08	7.28	7.23	0.14
Glycine	3.84	4.07	4.18	4.59	4.17	0.31
Hydroxylysine	0.11	0.14	0.16	0.10	0.13	0.03
Hydroxyproline	0.71	0.81	0.99	1.34	0.96	0.28
Ornithine	0.20	0.15	0.15	0.08	0.15	0.05
Proline	3.05	3.14	3.22	3.26	3.17	0.09
Serine	2.19	2.13	1.87	1.77	1.99	0.20
Tyrosine	1.86	2.03	1.77	1.85	1.88	0.11
Amino acid score	81	6	58	55		
First limiting amino acid	MET	TAU	TAU	TAU		

[1] One lot per age was analyzed.

Table 6.11 Macronutrient and energy composition of commercially obtained whole prey quail (presented as mean ± SD)[1]

Item	Age (d)											
	1 to 3			21 to 40			> 60			Mean	±	SD
Dry matter (DM), %	23.29	±	1.73	27.29	±	0.60	30.18	±	0.80	26.92	±	3.16
Organic matter, % DM	89.65	±	2.10	86.27	±	2.35	86.15	±	3.58	87.35	±	2.94
Crude protein, % DM	65.59	±	1.78	74.55	±	0.11	69.61	±	2.44	69.92	±	4.17
Acid hydrolyzed fat, % DM	26.28	±	1.34	12.88	±	1.46	18.57	±	2.28	19.24	±	6.02
Total dietary fiber, % DM	0.65	±	0.56	0.84	±	0.83	1.33	±	0.66	0.94	±	0.67
Gross energy, kcal/g DM	6.51	±	0.31	5.62	±	0.17	5.77	±	0.08	5.87	±	0.45

[1] Three lots per age were analyzed.

Table 6.12 Mineral composition of commercially obtained whole prey quail[1]

	Age (d)			Mean	SD
Item	1 to 3	21 to 40	> 60		
Ca, % dry matter (DM)	2.79	2.36	1.34	1.95	0.53
P, % DM	1.51	1.30	1.13	1.47	0.30
Ca:P ratio	1.84	1.82	1.19	1.32	0.11
K, % DM	0.40	0.35	0.66	0.86	0.18
Na, % DM	0.21	0.15	0.63	0.40	0.20
Cl, % DM	0.16	0.11	0.77	0.52	0.23
Mg, % DM	0.07	0.05	0.07	0.10	0.03
Fe, mg/kg DM	83	101	148	142.67	5.51
Cu, mg/kg DM	4	9	5	7.33	2.08
Mn, mg/kg DM	3	2	3	9.67	6.11
Zn, mg/kg DM	57	50	81	79.33	6.66
S, % DM	0.41	0.27	0.81	0.78	0.04

[1] One lot per age was analyzed.

Table 6.13 Amino acid (AA) composition of commercially obtained whole prey quail[1]

	Age (d)				
Item	1 to 3	21 to 40	> 60	Mean	SD
AA, % DM	60.47	73.54	65.00	66.34	6.64
Total essential AA	28.17	35.12	30.80	31.36	3.51
Arginine	4.18	5.06	4.41	4.55	0.46
Histidine	1.53	1.87	1.66	1.69	0.17
Isoleucine	2.52	3.42	2.92	2.95	0.45
Leucine	4.73	6.00	5.24	5.32	0.64
Lysine	3.87	5.35	4.67	4.63	0.74
Methionine	1.33	1.60	1.46	1.46	0.14
Phenylalanine	2.77	3.20	2.84	2.94	0.23
Taurine	0.65	0.54	0.52	0.57	0.07
Threonine	2.60	3.07	2.82	2.83	0.24
Tryptophan	0.59	0.69	0.53	0.60	0.08
Valine	3.41	4.32	3.74	3.82	0.46
Total non-essential AA	32.29	38.41	34.20	34.97	3.13
Alanine	3.43	4.22	3.78	3.81	0.40
Aspartate	5.21	6.37	5.74	5.77	0.58
Cysteine	1.36	1.62	1.39	1.46	0.14
Glutamate	7.42	9.98	8.53	8.64	1.28
Glycine	4.69	4.89	4.43	4.67	0.23
Hydroxylysine	0.12	0.07	0.14	0.11	0.04
Hydroxyproline	0.82	0.67	0.76	0.75	0.08
Ornithine	0.11	0.11	0.10	0.11	0.01
Proline	3.71	4.32	3.82	3.95	0.33
Serine	3.05	3.36	3.07	3.16	0.17
Tyrosine	2.36	2.80	2.44	2.53	0.23
Amino acid score	107	105	97		
First limiting amino acid	MET	MET	TRP		

[1] One lot per age was analyzed.

Table 6.14 Macronutrient and energy composition of commercially obtained whole prey duck and chicken (presented as mean ± SD)[1]

Item	Duck	Chicken		
	Ground	1 to 3 d	Ground	Mean ± SD
Dry matter (DM), %	37.04 ± 4.61	22.87 ± 1.16	27.51 ± 2.15	25.19 ± 2.97
Organic matter, % DM	88.64 ± 2.83	91.07 ± 0.54	87.37 ± 2.83	89.22 ± 2.72
Crude protein, % DM	39.61 ± 6.82	71.90 ± 1.67	54.47 ± 4.00	63.19 ± 9.93
Acid hydrolyzed fat, % DM	50.60 ± 7.80	19.89 ± 1.22	34.35 ± 2.47	27.12 ± 8.11
Total dietary fiber, % DM	1.83 ± 1.29	1.19 ± 1.23	2.39 ± 1.46	1.79 ± 1.37
Gross energy, kcal/g DM	6.98 ± 0.51	6.20 ± 0.61	6.28 ± 0.21	6.24 ± 0.41

[1] Three lots per age were analyzed.

Table 6.15 Mineral composition of commercially obtained whole prey duck and chicken[1]

	Duck	Chicken			
Item	Ground	1 to 3 d	Ground	Mean	SD
Ca, % dry matter (DM)	2.36	1.49	2.79	2.14	0.92
P, % DM	1.30	0.95	1.51	1.23	0.40
Ca:P ratio	1.82	1.57	1.84	1.71	0.19
K, % DM	0.35	0.63	0.40	0.52	0.16
Na, % DM	0.15	0.66	0.21	0.44	0.32
Cl, % DM	0.11	0.87	0.16	0.51	0.51
Mg, % DM	0.05	0.07	0.07	0.07	0.00
Fe, mg/kg DM	101	102	83	92.50	13.44
Cu, mg/kg DM	9	4	4	4.00	0.00
Mn, mg/kg DM	2	2	3	2.50	0.71
Zn, mg/kg DM	50	59	57	58.00	1.41
S, % DM	0.27	0.89	0.41	0.65	0.34

[1] One lot per age was analyzed.

Table 6.16 Amino acid (AA) composition of commercially obtained whole prey duck and chicken[1]

	Duck	Chicken			
Item	Ground	1 to 3 d	Ground	Mean	SD
AA, % DM	30.96	70.65	50.59	60.62	14.18
Total essential AA	13.85	32.49	21.58	27.04	7.71
Arginine	2.16	4.87	3.54	4.21	0.94
Histidine	0.70	1.63	1.20	1.42	0.30
Isoleucine	1.29	2.99	1.92	2.46	0.76
Leucine	2.29	5.38	3.40	4.39	1.40
Lysine	2.32	4.45	3.47	3.96	0.69
Methionine	0.70	1.52	1.13	1.33	0.28
Phenylalanine	1.24	3.20	1.92	2.56	0.91
Taurine	0.15	0.73	0.22	0.48	0.36
Threonine	1.07	2.83	1.86	2.35	0.69
Tryptophan	0.35	0.76	0.55	0.66	0.15
Valine	1.59	4.12	2.38	3.25	1.23
Total non-essential AA	17.11	38.17	29.01	33.59	6.48
Alanine	2.12	4.17	3.49	3.83	0.48
Aspartate	2.69	5.99	4.25	5.12	1.23
Cysteine	0.36	1.56	0.50	1.03	0.75
Glutamate	4.33	9.07	6.63	7.85	1.73
Glycine	2.99	5.61	5.43	5.52	0.13
Hydroxylysine	0.11	0.22	0.14	0.18	0.06
Hydroxyproline	0.83	1.21	1.89	1.55	0.48
Ornithine	0.04	0.08	0.07	0.08	0.01
Proline	2.01	4.43	3.54	3.99	0.63
Serine	0.76	3.37	1.54	2.46	1.29
Tyrosine	0.88	2.47	1.55	2.01	0.65
Amino acid score	93	104	88		
First limiting amino acid	CYS + MET	MET	CYS + MET		

[1] One lot per age was analyzed.

CHAPTER 7: CONCLUSION

Great advances in feline nutrition (i.e., nutritional requirements, disease management via dietary intervention) have been made over the last several decades. Felids are obligate carnivores, and evolutionary influence of a strictly carnivorous diet has resulted in specialized metabolic pathways and nutritional requirements. Animal prey are compositionally high in protein and low in carbohydrate, providing a high quality, energy dense diet (Morris et al., 2006).

For captive exotic felids, the predominant diet types fed are raw meat-based and whole prey diets. These diet types are not the most common fed to domestic cats, but there has been an increased popularity in feeding "natural" and alternative diet types, including those composed of raw meat and whole prey. Despite their popularity, however, these diets have not been adequately studied in domestic or exotic felids. Specifically, there is a paucity of peer-reviewed literature examining nutrient composition, apparent total tract macronutrient digestibility, and bioavailability of raw meat-based and whole prey diets in felids. An additional challenge is the lack of knowledge regarding the nutrient requirements of felids, especially those for captive exotic felids. The nutrient requirements of domestic cats most often are used as a guide for captive exotic felids.

In captivity or a home setting, a felid's diet is provided solely by the zoo staff or pet owner, respectively. As such, they have a responsibility to provide all of the nutrients necessary for cellular repair, growth, and health management. Without adequate testing and knowledge of raw meat-based and whole prey diets, including their ability to meet the requirements of the domestic cat, this may not be possible.

A majority of research pertaining to raw diets has focused on raw beef- and horsemeat-based diets, with little research focused on alternative protein sources (e.g., other species, whole prey diets) or other dietary ingredients (e.g., fiber sources and concentrations, micronutrients).

The overall objective of this research was to evaluate raw meat and whole prey diets for use in domestic and captive exotic cat diets, including diet compositional analyses, and effects on measures of blood metabolites, nutrient digestibility, N metabolism, microbiota composition, and fermentative end-products. The examination of commercially available alternatives herein, including raw meat sources, whole prey items, and fiber sources, provides important data regarding their interactions and effects on dietary composition, macronutrient digestibility, and bioavailability.

Our first aim, presented in Chapter 3, was to evaluate traditional (beef; horse) and alternative (bison; elk) protein sources for use in raw meat-based diets for captive exotic and domestic felids. Diets were analyzed for nutrient composition, including amino acid and fatty acid concentrations, and protein quality was assessed using the cecectomized rooster assay. Nitrogen metabolism and fecal fermentative end-product concentrations were examined in the domestic cat, and apparent total tract macronutrient digestibility was determined in the domestic cat and three captive exotic cat species.

Our second aim, presented in Chapter 4, was to evaluate common fiber types and concentrations utilized in raw meat-based diets for captive exotic felids. We evaluated cellulose and beet pulp as fiber sources, including each at 2 or 4% of the diet. We examined apparent total tract macronutrient digestibility and fecal fermentative end-products in four captive exotic cat species.

Our third aim, presented in Chapters 5 and 6, was to determine nutrient composition and digestibility of common whole prey items fed to captive exotic felids. Firstly, we compared apparent total tract macronutrient digestibility of whole-prey chicks, whole ground chicken, a chicken-based canned diet, and a chicken-based extruded diet in African wildcats and domestic cats. In addition to nutrient digestibility measurements in domestic cats, we also measured blood metabolites and fecal-fermentative end-products. Our final study determined the nutrient composition of 20 commercially available prey items used in raw meat and whole prey diets. Diets were analyzed for macronutrient, amino acid, and mineral concentrations.

In general, all diets were well-utilized by all exotic and domestic felids, regardless of protein source, fiber type and concentration, or processing method. All animals were able to maintain body condition while fed these raw meat or whole prey diets. Additionally, when fed raw meat-based, whole prey, or traditional canned or extruded diets, domestic cats maintained BW, N balance, and the majority of blood metabolites remained within reference ranges (Chapters 3 and 5). Digestible energy of these diets ranged from 83 to 95%. Metabolizable energy intakes (67 to 120 kcal/d/kg $BW^{0.75}$; Chapters 4 and 5) were within the range recommended by NRC (2006) for captive exotic felids (55 to 250 kcal/d/kg $BW^{0.75}$). Given the large range and generality of the ME intake recommendations provided for captive exotic felids, currently it has little bearing in a practical setting. Our data may contribute to defining species-specific recommendations in the future.

In Chapter 3, we determined that traditional (beef trimmings; horse trimmings) and alternative (elk meat; bison trimmings) protein sources utilized in raw-meat based diets containing cellulose had high apparent total tract OM and CP digestibilities (>85% and > 95%, respectively) in domestic and captive exotic cats, standardized amino acid digestibility in

roosters (total essential amino acid digestibility > 90%), and amino acid scores (81 to 95). In Chapter 4, we demonstrated that by increasing the inclusion of cellulose (2 vs. 4%), a non-fermentable fiber source in place of beef trimmings, apparent total tract OM digestibility was decreased (86% vs. 80%) in captive exotic species without impacting apparent total tract CP digestibility (95%). Inclusion of beet pulp, a fermentable fiber, however, did not affect apparent total tract OM digestibility (85 to 87%), but decreased apparent total tract CP digestibility (93%) compared to cats fed cellulose (95%). The decreased apparent total tract CP digestibility was likely due to increased fermentation, leading to increased bacterial protein production in the large bowel and an underestimation of apparent CP digestibility. Additionally, apparent total tract DM, OM, fat, and GE digestibility decreased linearly with BW independent of fiber type. Apparent total tract CP digestibility decreased linearly with BW when exotic cats were fed beet pulp, but not when fed cellulose. These data indicate that larger cats are more sensitive to fermentable fiber.

Apparent total tract digestibility of whole prey diets by domestic and African wildcats was not as clear cut (Chapter 6). When comparing apparent total tract OM digestibility in traditional canned (86 to 87%) and extruded (86 to 88%) diets, whole ground chicken (excluding feathers) was highly digestible (94%), while whole 1 to 3 d-old chicks had a lower digestibility (83 to 85%). Differences between the whole prey types could be due to many factors, including age and processing (e.g., ground vs. whole) of prey. Future research should focus on determining the importance of these factors in whole prey feeding.

The high digestibility of the whole ground chicken diet, combined with low fiber concentrations or bulking materials (i.e., feathers), resulted in dry hard fecal samples in the domestic and African wildcats fed this diet. Cats fed the 1 to 3 d-old chicks, canned diet, and

extruded diet had fecal scores near the ideal range (2.6 to 3.6; 3 = ideal). We noted similar results in cats fed raw meat-based diets. When jaguars (Chapter 4) were fed raw diets containing 2% cellulose, fecal samples were harder and drier than ideal. When beet pulp was included in the diets of jaguars, however, fecal scores were improved. These data indicate that the inclusion of fiber or fiber-like materials is necessary to maintain fecal quality in small to mid-sized felines.

On the other hand, larger cats (i.e., Malayan tigers and Siberian tigers) had ideal fecal scores when fed raw diets containing cellulose (Chapters 3 and 4), but loose stools when fed raw diets containing beet pulp (Chapter 4). The positive correlation between poor fecal quality and larger body size also has been reported in dogs [small vs. large and giant breed dogs (Weber et al., 2004; Hernot et al., 2004; 2005; 2006)]. It has been suggested that the differences reported in the dogs may be linked to longer transit time, increased intestinal permeability, or increased fermentative activity in the large bowel of large-breed dogs. However, research examining these differences in felid species is limited.

The effects of diet and species are also important as regards fecal short-chain fatty acids (SCFA) and putrefactive concentrations. Production of SCFA (butyrate, in particular) is considered beneficial, while the production of putrefactants in humans and pets is considered negative. Exotic cats fed diets containing beet pulp had decreased fecal pH, and increased fecal SCFA, branched-chain fatty acids (BCFA), and ammonia concentrations compared to cats fed diets containing cellulose (Chapter 4). These changes were likely due to a combination of the higher fermentability and water-holding capacity of beet pulp and the fecal bulking / dilution effects of cellulose. Additionally, for Siberian tigers, it appeared that higher fiber inclusion (4%) may be important for modulating protein fermentation and decreasing fecal putrefactive compounds (i.e., phenol and BCFA). An increased understanding on the interactions between

fiber type, fiber concentration, and species, and how it impacts fecal characteristics, is needed. These data will allow for species-specific diet formulations to be created, optimizing animal health and cat management in zoos.

An additional area that must be examined to optimize diet formulation is nutrient composition. All diets contained adequate concentrations of CP, and a majority had adequate amino acid concentrations; however, taurine concentrations were low in whole prey rabbits (Chapter 6). Another area of concern is total fat concentration. Specifically, trimmed elk muscle meat (Chapter 3) was deficient in fat, indicating that when muscle meats are used as the primary protein source, an additional fat source may be necessary. In Chapter 3, we also determined that while all raw meat-based diets were adequate sources of α-linolenic acid, none of the diets met the linoleic acid concentrations recommended by the NRC (2006). Additional deficiencies were observed for EPA, DHA, and arachidonic acid. In Chapter 6, we observed that a majority of whole prey samples had mineral (K, Na, Cl, Mg, Cu, Mn, Zn) concentrations below recommendations by AAFCO (2012) for domestic cats. Feeding diets long-term with nutrient deficiencies will have negative impacts on health, including but not limited to poor skin and coat health, poor growth and reproduction, and bone and joint disorders. For these reasons, it is important to obtain nutrient profiles of dietary constituents, including whole prey items prior to long-term feeding. When nutrient deficiencies are identified, alterations in the ingredient preparation (i.e., diet of whole prey, inclusion criteria) or supplementation are necessary. Therefore, cats should only be fed whole prey and raw meat ingredients as a part of a properly balanced diet.

Although our research has answered many questions about raw meat-based and whole prey diets for domestic cats and captive exotic felids, more research in feline nutrition is needed.

An important area of research for the future will be further examination of dietary fiber and its use in raw meat-based diets. A better understanding of the proper blend of fermentable and non-fermentable fibers for small vs. large species is needed. Additionally, the interaction of dietary fiber and protein should be investigated. Some areas of interest include differing dietary protein concentrations, and the comparison of dietary fiber and fiber-like materials present in whole prey. Efforts also should be made to elucidate the nutrient and energy requirements of domestic and captive exotic felids, and the ability of whole prey diets to meet those requirements. The potential to modify whole prey composition by varying their diet composition should also be evaluated. These data, similar to that reported herein, would provide information that would improve diet formulation of raw meat-based and whole prey diets.

CHAPTER 8: LITERATURE CITED

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