Natural pet food: A review of natural diets and their impact on canine and feline physiology

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ABSTRACT: The purpose of this review is to clarify the definition of "natural" as it pertains to commercial pet food and to summarize the scientific findings related to natural ingredients in pet foods and natural diets on the impact of pet health and physiology. The term "natural," when used to market commercial pet foods or pet food ingredients in the United States, has been defined by the Association of American Feed Control Officials and requires, at minimum, that the pet food be preserved with natural preservatives. However, pet owners may consider natural as something different than the regulatory definition. The natural pet food trend has focused on the inclusion of whole ingredients, including meats, fruits, and vegetables; avoiding ingredients perceived as heavily processed, including refined grains, fiber sources, and byproducts; and feeding according to ancestral or instinctual nutritional philosophies. Current scientific evidence supporting nutritional benefits of natural pet food products is limited to evaluations of dietary macronutrient profiles, fractionation of ingredients, and the processing of ingredients and final product. Domestic cats select a macronutrient profile (52% of ME from protein) similar to the diet of wild cats. Dogs have evolved much differently in their ability to metabolize carbohydrates and select a diet lower in protein (30% of ME from protein) than the diet of wild wolves. The inclusion of whole food ingredients in natural pet foods as opposed to fractionated ingredients may result in higher nutrient concentrations, including phytonutrients. Additionally, the processing of commercial pet food can impact digestibility, nutrient bioavailability, and safety, which are particularly important considerations with new product formats in the natural pet food category. Future opportunities exist to better understand the effect of natural diets on health and nutrition outcomes and to better integrate sustainable practices in the production of natural pet foods.

Key words: companion animal, food, natural, nutrition, metabolism

INTRODUCTION

Throughout history, humans have associated with dogs and cats in various ways, including protection, rodent control, hunting, and companionship. Diets of dogs and cats have shifted, as a result of domestication, from hunting and scavenging to diets formulated for their specific nutritional requirements. Changes in human diets through the development of agricultural practices have fostered this shift. In the United States, 63% of pet owners consider their pets to be family members (AVMA, 2012b). Anthropomorphism of dogs and cats has resulted in pet owner preference for pet foods containing ingredients that they find in their own diet and processed in a way to maintain the nutritional integrity of the ingredients and ensure food safety. Contemporary trends in human diets in developed regions of the world are including more fresh fruits and vegetables (Barnard, 2010) and whole grains (Griffiths, 2010). This paradigm has resulted in the emergence of the natural pet food segment. The natural pet food segment in the United States has grown steadily, from US$2.0 billion in 2008 to $3.9 billion in 2012 (Lummis, 2012).

The expansion of the natural pet food segment has led to a wide spectrum of products with different nutritional strategies applied across brands and introducing unique philosophies on what defines a natural pet food product (Lummis, 2012). This variability has led to confusion and disagreement as to the true definition of natural pet foods and natural pet nutrition. Additionally, the application of human food trends often is used to

support functional health benefits of natural pet food products despite limited scientific evidence supporting the benefits in companion animals. Therefore, the purpose of this review is to clarify the definition of natural as it pertains to commercially manufactured pet foods and summarize the scientific findings regarding natural ingredients used regarding their impact on pet health and physiology. It should be noted, however, that although home-prepared diets may meet certain definitions of natural, they will not be discussed here because these are not officially recognized by any regulatory agency.

REGULATORY DEFINITIONS OF NATURAL

Pet food manufacturers must meet the regulatory definition of natural to market a pet food as natural. The definition of natural applies to both pet food ingredients and pet food products. However, regulatory agencies internationally disagree on the definition of natural. Consider, for example, differences that exist between the United States and European definitions of natural as it applies to pet food ingredients or products. In the United States, the regulatory definition of natural has been developed by the Association of American Feed Control Officials (**AAFCO**), a voluntary membership association of state feed officials charged with developing model regulations to be adopted by states to regulate animal feeds and animal drug remedies. The AAFCO definition of natural states the following:

> …A feed or ingredient derived solely from plant, animal or mined sources, either in its unprocessed state or having been subject to physical processing, heat processing, rendering, purification, extraction, hydrolysis, enzymolysis or fermentation, but not having been produced by or subject to a chemically synthetic process and not containing any additives or processing aids that are chemically synthetic except in amounts as might occur unavoidably in good manufacturing practices. (AAFCO, 2013)

Synthetic trace nutrients are allowed by the AAFCO in natural pet foods as long as they have nutritive value. In this case, a disclaimer on the package is used to inform the consumer that the vitamins, minerals, or other trace nutrients are not natural (AAFCO, 2013). This enables the formulation of complete and balanced natural pet food products. A complete and balanced diet should have all essential nutrients in the proper amount and proportions based on authoritative recommendations, such as the NRC (NRC, 2006). Guidelines for nutrient profiles for both dogs and cats by which a food may be considered complete and balanced are provided by the AAFCO (2013). The complete and balanced statement on the label indicates the formula provides all the essential nutrients necessary to maintain life (except water) when fed as the sole source of energy in the diet.

The European Union use of the term natural is defined by The European Pet Food Industry Federation (**FEDIAF**) and states

> The term "natural" should be used only to describe pet food components (derived from plant, animal, microorganism or minerals) to which nothing has been added and which have been subjected only to such physical processing as to make them suitable for pet food production and maintaining the natural composition. (FEDIAF, 2011)

Processing of components including freezing, concentration, extraction (without chemicals), drying, pasteurization, or smoking (without chemicals) is acceptable as far as is maintains the natural composition. Microbiological and enzymatic processes, hydrolysis, or natural fermentation processes (without the use of genetically modified organisms) are acceptable with the use of the term natural (FEDIAF, 2011). Similar to the AAFCO definition, the FEDIAF definition allows the use of synthetic vitamins and minerals with an appropriate disclaimer. Additionally, guidelines for nutrient profiles for both dogs and cats by which a food may be considered complete and balanced are provided by the FEDIAF (2011).

Given the above definitions, it is noteworthy that there are distinct differences between the AAFCO and FEDIAF approaches to defining natural. While both allow many of the same processes, the FEDIAF definition excludes the use of chemical processing aids and requires that processing does not change the natural composition of the ingredient. For example, under the AAFCO definition, hexane-extracted soybean oil is considered a natural pet food ingredient since the hexane is not present in the final ingredient except in amounts as might occur unavoidably in good manufacturing practices. However, according to the FEDIAF definition, hexane-extracted oil would not be considered natural since it uses chemical extraction. Conversely, cold pressed oil would be considered natural according to the FEDIAF definition because it does not use chemical extraction. An example of an instance where the natural composition of an ingredient is not maintained is carrot pulp from which carotene has been extracted. According to the FEDIAF definition, this would not be considered a natural ingredient because the natural composition has changed; however, this may be considered a natural ingredient according to the AAFCO definition. Another difference in regulatory definitions is that the use of genetically modified ingredients in natural products is currently not addressed in the AAFCO definition of natu-
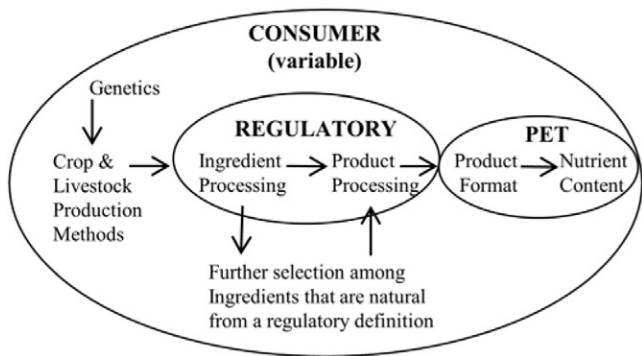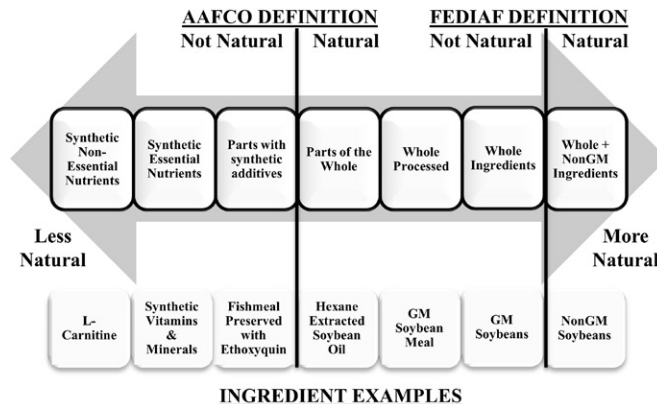
Figure 1. Pet food manufacturing process steps considered by different entities for defining "natural." Labels within a circle represent the regulatory consideration of the Association of American Feed Control Officials definition of natural, consumer perspectives of natural, and natural pet nutrition concepts based on pet physiology and preferences.

Figure 2. The continuum of natural ingredients. The Association of American Feed Control Officials (AAFCO) and The European Pet Food Industry Federation (FEDIAF) regulatory definitions of natural are highlighted along the continuum. Examples of pet food ingredients are given for each step of the continuum. GM = Genetically Modified.

ral but is excluded by the FEDIAF definition. The difference between these definitions is instrumental to defining natural ingredients in today's global marketplace and underscores both the functional and regulatory characterizations of natural pet foods for dogs and cats. As such, it presents an ongoing challenge for natural pet food product formulation because it necessitates a different approach to product formulation in different regions of the world.

NATURAL BEYOND THE REGULATORY DEFINITIONS

Inconsistencies in the definition of natural among international regulatory agencies and the lack of visibility and understanding of regulatory definitions by pet owners have contributed to misperceptions about natural pet food products. Therefore, many natural pet food consumers seek out products or ingredients with claims of human-grade, organic, holistic, ancestral, or instinctual and avoid ingredients perceived as fillers or byproducts (Shmalberg, 2013); however, these terms are not addressed in the current regulatory definitions of natural.

Each step of the manufacturing process of pet food can positively or negatively affect the naturalness of the final product, including crop and livestock production activities, ingredient processing and preservation, and kibble extrusion or canning of final product (Fig. 1). Consequently, various steps of the manufacturing process are considered by pet owners, manufacturers, nutritionists, or regulatory agencies when determining if an ingredient or product is natural. For example, the AAFCO definition of natural primarily considers ingredient processing, whereas consumers may impose additional selection criteria based on opinions and beliefs, such as exclusion of ingredients perceived as having low nutritional value. On the other hand, consumers, nutritionists, or manufacturers that determine a natural diet based on pet physiology or pet preference may consider nutrient composition, food format, or ingredient origin (e.g., plant vs. animal).

Differences in natural ingredient processing highlight the difficulties in classifying ingredients or pet food products as natural. Therefore, identifying natural ingredients is a complex process in which it is critical to have a thorough understanding of ingredients through their production, preparation, processing, and preservation. Even within ingredient processing techniques, there is a continuum of what may be considered more or less natural (Fig. 2). For example, an identical raw material can be processed either as a whole ingredient, fractionated to isolate specific parts of the ingredient, or stabilized by adding synthetic preservatives. According to the AAFCO definition of natural, the whole cooked ingredient and fractionated ingredients would be considered natural but the synthetically preserved ingredient would not. However, from a consumer standpoint the defining of the ingredient as natural may not be as clear-cut. Many consumers would consider the whole cooked ingredient as natural but not the fractionated or synthetically preserved ingredient.

IMPACT ON PET HEALTH

Natural Diets

Natural diets, including instinctual or ancestral diets, are based on feeding pets according to their physiological capabilities or preferences, rather than simply meeting the regulatory definition of a natural pet food product. Instinctual diets are based on the philosophy of feeding pets according to their innate preferences, with the assumption that animals will self-select foods to meet their nutritional needs. Ancestral diets are based on the philosophy of feeding pets a diet similar to evolutionary

ancestors, with the assumption that such a diet aligns with the physiological needs and metabolic capabilities of companion animals. Regardless of philosophical basis, both instinctual and ancestral diets typically contain higher protein and lower carbohydrate concentrations than the majority of dry pet foods on the market. There are no regulatory definitions of instinctual or ancestral diets; therefore, the nutrient composition of commercial pet food products may not accurately apply to instinctual or ancestral nutritional philosophies.

Instinctual Diets. Recent research using nutritional geometry in a controlled environment has demonstrated that dogs of various breeds select a macronutrient profile in which 30% of their ME comes from protein, 63% from fat, and 7% from carbohydrates (Hewson-Hughes et al., 2013). Similar research in cats indicates they select 52% of their ME from protein, 36% from fat, and 12% from carbohydrates (Hewson-Hughes et al., 2011). Given their strict carnivorous nature, it is not surprising that cats show a preference for higher protein diets compared to omnivorous dogs. By contrast, dogs apparently find dietary fat particularly palatable, which is consistent with minimal adverse health effects of high fat diets in healthy populations of dogs (Bauer, 2006). However, it is unknown whether the above distributions of macronutrients would provide optimal nutrition, given that the preferred macronutrient levels are substantially different than minimal requirements or recommended allowances outlined by the NRC (NRC, 2006).

Ancestral Diets. It is recognized that domesticated dogs evolved from wolves (*Canis lupus lupus*; Serpell, 1995). From archeological evidence, it is believed dogs were the first animal to be domesticated by humans around 14,000 yr ago (Clutton-Brock, 1995). Domestication of cats is more recent than dogs, as remains of cats dating back 6,000 yr ago have been found in Cyprus (Serpell, 2000). Consequently, some natural dog foods are marketed based on high meat and protein formulations believed suitable for wolves due to their evolutionary connection and genetic similarities. However, domesticated dogs are no longer wolves because domestication as *Canis lupus familiaris* has modified not only their social and cognitive attributes but also the types of foodstuffs that are suitable for them (Hemmer, 1990). Recent evidence has been reported in which candidate mutations in key genes of dogs compared to wolves provide functional support for increased capability for starch digestion (Axelsson et al., 2013) compared to the carnivorous wolf diet (Stahler et al., 2006). This supports a previous report by Serpell (1995) that dogs descended from a subset of wolves that had been more socially adapted to human contact. These data help explain the omnivorous nature of domestic dogs versus carnivorous wolves.

In nature, it appears the primary component of the canine diet is animal protein, but as noted above, domestic canines can obtain nutritional requirements from plant sources as well. Feral dogs are known to hunt in packs, similar to wild canines, and eat a wide variety of foods. The diet of wolves consists primarily of animal protein and they typically hunt larger prey, such as elk, eating the nutrient-dense organs first followed by muscle tissue (Stahler et al., 2006). Analysis of 50 diets consumed by wolves revealed average nutrient intake of 35.5 g protein, 13.2 g fat, and 0.8 g carbohydrate per MJ ME, which reflects a macronutrient profile of 52% ME from protein, 47% ME from fat, and 1% ME from carbohydrate (Hendriks, 2013). Feral dogs typically hunt small prey and forage on berries and some plants (Boitani and Ciucci, 1995). Jackals (*Canis aureus*) often raid stores of cultivated fruit and consume large quantities of grass (Ewer, 1973). Wild canines and feral dogs must exert a considerable amount of energy to acquire food and therefore consume foods that are more easily available in the environment in which they live. This evidence supports the hypothesis that canine species are highly adaptable to various diets, and the diet they choose is dictated by the environment in which they live.

Through mitochondrial DNA analysis, it has been reported that the domestic cat (*Felis catus*) is most closely related to the European wildcat (*Felis silvestris*), the African wildcat (*Felis libyca*), and the sand cat (*Felis nigripes*; Johnson and O'Brien, 1997). These species of wild cats closely resemble the domestic cat in appearance, and African wildcats have been kept as pets (Smithers, 1968). Many of the behavioral signs observed in domestic cats, such as purring, meowing, hissing, and spitting, have been observed in most wild species (Serpell, 2000).

The natural diet of feral cats consists primarily of small mammals, birds, fish, reptiles, and invertebrates, with a macronutrient profile of 52% ME from protein, 46% ME from fat, and 2% ME from carbohydrate (Plantinga et al., 2011). Studies on the preferred macronutrient profile of domestic cats indicate the instinctual dietary preference of domestic cats closely resembles the nutrient composition of cats in the wild (Hewson-Hughes et al., 2011). Studies have been conducted comparing the digestibility of various raw meat based diets of captive exotic felids to domestic cats. Vester et al. (2010) reported apparent total tract digestibility in cheetahs (*Acinonyx jubatus*), jaguars (*Panthera onca*), Malayan tigers (*Panthera tigris corbetti*), Amur tigers (*Panthera tigris altaica*), and domestic short hair cats (*F. catus*) consuming 2 different raw meat based diets. These investigators found no differences in digestibility measure between the captive exotic felids. Differences between domestic cats and jaguars were observed for DM, CP, fat, and GE digestibilities ($P < 0.05$). Differences were also observed between domestic cats and

Amur tigers for DM, OM, CP, fat, and GE digestibility ($P < 0.05$). Additionally, differences were observed between domestic cats and Malayan tigers for CP, fat, and GE digestibilities ($P < 0.05$). No differences were observed between domestic cats and cheetahs. A later report from the same laboratory (Kerr et al., 2013) compared total tract digestibility of domestic cats, African wildcats (*Felis silvestris tritrami*), jaguars, and Malayan tigers fed meat based raw diets. In this study, there were no observed differences between species for total tract DM, OM, and GE digestibilities. However, they did find differences between apparent total tract CP digestibility between domestic cats and Malayan tigers, but no differences in CP digestibility were observed between domestic cats and other species in this study. Unlike the evolution of dogs, cats appear to have retained much of the dietary preference, behavioral attributes, and physiological digestive function as the wild species. More research needs to be conducted to determine impact of ancestral diets on health of pets.

Pet Physiology and Metabolism. The basis behind feeding natural diets, including instinctual and ancestral diets, is to meet nutritional needs and align with physiological and metabolic capabilities to promote health in companion animals. Therefore, to better evaluate the extent to which such diets are appropriate for companion animals, some appreciation of both dog and cat digestive physiology is important.

Both dogs and cats have the ability enzymatically (maltase, sucrose, and lactase) to digest carbohydrates (Hore and Messer, 1968). Morris et al. (1977) showed cats are able to efficiently digest glucose, sucrose, lactose, dextrin, and starch (apparent digestibility 94–100%). Additionally, cats have been reported to have lower enzymatic activities for carbohydrate digestion compared to other species (Kienzle, 1993a,b,c,d) and physiologic responses differ by carbohydrate type and thermal processing (Kienzle, 1994). These results indicate that although cats have the ability to efficiently digest carbohydrates, their capacity for carbohydrate digestion may be limited, as evidenced by digestive disorders, such as diarrhea, flatulence, and bloating, when high concentrations of carbohydrates (>5 g/kg BW) are fed (Kienzle, 1993b).

Relative to humans, dogs have an increased capacity for fat oxidation, generating twice the amount of energy from fat oxidation at rest and during exercise (McClelland et al., 1994). However, dogs have responses similar to humans in carbohydrate metabolism following a meal, with carbohydrate amount and type dictating glycemic response (Nguyen et al., 1998; Carciofi et al., 2008; Elliott et al., 2012). For example, when 12 working hounds were fed a high protein (49%), low carbohydrate (13%) diet they had a delayed peak glucose concentration and sustained glucose response compared

to when fed a lower protein (22%), higher carbohydrate (45%) diet (Hill et al., 2009).

The metabolism of cats is adapted for gluconeogenesis rather than glucose clearance, including no detectable hepatic glucokinase activity and higher activities of pyruvate carboxylase, fructose-1,6-biphosphatase, and glucose-6-phosphatase in feline compared to canine livers (Washizu et al., 1999; Tanaka et al., 2005). However, there is currently limited evidence to suggest that moderate concentrations of carbohydrates in the diet are detrimental to the metabolism or health of cats (Verbrugghe et al., 2012). For example, both high (47% energy from carbohydrate compared to 26–27%) or low (7% energy from carbohydrate compared to 25–29%) concentrations of dietary carbohydrate reduce insulin sensitivity in cats (Farrow et al., 2002; Verbrugghe et al., 2010). Additionally, while protein intake of 48 versus 28% energy from protein does not affect insulin sensitivity (Leray et al., 2006), high concentrations of dietary fat (51% energy from fat compared to 33%) reduces glucose tolerance in cats (Thiess et al., 2004).

Although protein or essential AA intakes beyond the recommended allowance (NRC, 2006) have not been reported to provide added benefit for pets requiring maintenance nutrient needs, there is evidence to suggest a benefit during physiological states other than adult maintenance, such as obesity and athletic training. High protein diets (>100 g crude protein/1,000 kcal ME) have been shown to effectively facilitate weight loss in obese dogs while maintaining lean body mass (Diez et al., 2002; Blanchard et al., 2004; German et al., 2010). Hoenig et al. (2007) investigated effects of a high-carbohydrate/low-protein (28% protein/38% carbohydrate) and a high-protein/low-carbohydrate (45% protein/25% carbohydrate) diet during weight loss. Weight loss modified selected hormones and other metabolites independent of diet. These investigators also found that the high protein diet was beneficial in cats to maintain normal insulin sensitivity of fat metabolism during caloric restriction. It should be noted that studies showing beneficial effects of higher protein diets in overweight or obese companion animals also used caloric restriction and often lower fat concentrations than natural diets to achieve these benefits.

Diets high in protein (>30% ME from protein) or fat (>50% ME from fat) have been shown to have a beneficial effect on exercise performance in dogs. Fat adaptation to greater than 50% of ME from fat was found to improve aerobic performance (Downey et al., 1980) and to spare glycogen utilization in dogs (Reynolds et al., 1995). Beagles ran for 20 miles (140 min) when fed high fat (53–67% of energy) diets but became exhausted after only 15 miles (100 min) when fed a moderate fat (29% of energy) diet (Downey et al., 1980). A high carbohydrate (60% ME from carbohydrate), low fat (15% ME from fat) diet fed

to sled dogs resulted in higher ($P < 0.05$) resting muscle glycogen concentrations compared with a high fat (60% ME from fat), low carbohydrate (15% ME from carbohydrate) diet, but the rate of glycogen utilization was greater ($P < 0.05$) during an anaerobic exercise bout; therefore, the final muscle glycogen concentration was unchanged (Reynolds et al., 1995). In racing sled dogs, protein concentration is also important, given there is progressive development of stress anemia below 32% ME from protein (Kronfeld et al., 1994). Conversely, moderate protein and fat (24% ME from protein, 33% ME from fat, and 43% ME from carbohydrate) has been shown to be more beneficial for sprint performance in dogs, as indicated by faster racing times (32.43 ± 0.48 vs. 32.61 ± 0.50 s; $P < 0.05$) over a 500-m distance (Hill et al., 2001).

The studies described above support the premise that canine and feline physiological and metabolic capabilities align with the preferred macronutrient levels of instinctual nutrition, which is particularly evident under physiological conditions of stress, such as aerobic exercise training. For cats, this also aligns with the macronutrient concentrations of ancestral nutrition. However, for dogs, ancestral nutrition specified by the diets of wolves is higher in protein and lower in fat and carbohydrates than preferences or physiology.

Further evidence is needed to support health benefits of natural diets for healthy, adult companion animals with maintenance requirements. There is a wide range of nutrient concentrations that may support optimal nutrition (Kronfeld et al., 1994). When the effect of increasing a selected nutrient on some specific performance measure is determined, an optimal plateau is often observed before declining at yet higher concentrations. Furthermore, the optimal range of a nutrient is broader during undemanding physiological states, such as maintenance, but becomes narrower during states of physiological stress, such as growth or exercise training. This is evident in dogs' and cats' ability to effectively and safely use a wide range of macronutrient levels, including higher carbohydrate and lower fat or protein than those specified by instinctual or ancestral nutrition.

Adjusting macronutrient levels to provide optimal nutrition is particularly relevant considering modern pet lifestyles, in which companion animals live primarily indoors and are less active than their wild predecessors. Feeding management becomes a critical issue in feeding natural diets high in protein and fat to sedentary pets, given the substantial evidence for negative health effects of weight gain (Lund et al., 2005, 2006). Additionally, feeding foods containing high concentrations of animal based protein negatively impacts the environmental sustainability of a diet (Reijnders and Soret, 2003). Including carbohydrate in pet foods aligns with the concept of nutritional sustainability by reducing the environmental impact of pet foods while supporting pet health and nutritional needs (for a complete review of this topic see Swanson et al., 2013). Partially meeting energy needs from carbohydrates while still meeting AA and fatty acid requirements allows for the moderate inclusion of more environmentally and economically costly protein and/or fat sources in a pet food, especially in cases where there is competition of certain sources for human food ingredients. Therefore, the potential health benefits of feeding natural diets, specific to an individual pet's lifestyle and health status, should be weighed against the potential health and environmental concerns of feeding a natural diet high in protein and fat Finally, where pet food manufacture is concerned, owner lifestyle must be matched against pet nutritional needs and feeding management. For example, some pets may be indoors for lengthy periods of time while owners are away. Therefore, physiologic patterns of defecation and urination may, of necessity, be different depending on a food's nutrient composition.

Whole Ingredients

Pet foods have historically been formulated based on nutrient content, given that animals have specific requirements for nutrients and not ingredients. However, in the natural pet food segment, there is an increased focus by consumers and pet food manufacturers on ingredients, especially whole ingredients. As it pertains to pet food ingredients, "whole" is defined as a physical form that is "complete, entire" (AAFCO, 2013). Consequently, a growing trend for natural pet foods to contain more whole ingredients, such as meat instead of meat meals, whole grains instead of refined grains, and fruit and vegetable inclusions, has emerged (Lummis, 2012).

The theory behind the beneficial health effects of whole ingredients is described by the concept of food synergy. Food synergy is based on the proposition that the action of the food matrix (i.e., the composite of naturally occurring food components) on biological systems is greater than or different from the corresponding actions of the individual food components (Jacobs et al., 2009). It stems from the idea that we do not have complete knowledge of food composition and some health effects may result from unidentified or underappreciated components. In this way, whole ingredients may provide health benefits that the individual fractionated ingredients or single nutrients cannot provide. Although the term food synergy may not be well known by consumers, the concept of whole ingredients providing health benefits has likely contributed to the interest in natural pet foods by pet owners and hence the increased market demand for whole ingredients in pet foods.

The health benefit in humans of phytonutrients from fruits and vegetables is an example of food synergy.

Epidemiological studies in humans indicate associations between fruit and vegetable intake with lower risk of cardiovascular disease in women (Liu et al., 2000). In a human population study, consumption of foods rich in phytonutrients as measured by phytonutrient index has been shown to decrease weight gain and adiposity (Mirmiran et al., 2012) and risk for metabolic syndrome (Bahadoran et al., 2012). Rodent and in vitro models have shown positive effects of food synergy from fruits on antiproliferative and anticarcinogenic activities (Jacobs et al., 2009). Drug-induced mammary tumor incidence in rats was reduced more by using the whole apple than only the flesh without the skin (Liu et al., 2005). Similarly, whole pomegranates had greater in vitro antiproliferative effects than did some of their individual constituents (Seeram et al., 2005). Importantly, as fruits and vegetables and their constituents are incorporated in pet foods, additional research is needed to understand the potential impact on pet health and well-being and the effect of processing on phytonutrient stability (Tiwari and Cummins, 2013).

Whole grains are added to pet food formulations to provide digestible carbohydrates and dietary fiber (de Godoy et al., 2013). The effects of whole grains as they relate to pet health and well-being have not been thoroughly evaluated. Of interest is that whole grains have greater concentrations of many nutrients, including fiber, vitamins, minerals, and phytonutrients, compared to refined grains (Okarter and Liu, 2010; Jonnalagadda et al., 2011). For example, nutrient analysis of whole brown rice and brewers' rice used in pet food revealed higher ($P < 0.05$) concentrations of ether extract fat, crude fiber, phosphorus, and potassium in whole brown rice compared to brewers' rice (Table 1). This may seem irrelevant given that the dietary formulation of pet foods is intended to account for total nutrient needs especially when similar nutrient concentrations in can be achieved with supplemental fiber and synthetic vitamins and mineral source. However, as in fruits and vegetables, grains contain many unique phytonutrients. Recent studies by Forster et al. (2012a) demonstrated excellent digestibility and acceptability in dogs fed a dry-extruded diet when substituting some wheat and corn with 25% cooked navy bean powder while controlling both macronutrient and micronutrient contents. In addition, these workers also observed similar whole dry cooked bean powder containing diets to provide nutritional weight loss therapy while regulating serum lipids and biochemical analytes in overweight and obese dogs (Forster et al., 2012b). In humans, whole grain consumption has been associated with lower risk of certain cancers such as colon cancer. Phytonutrients, such as ferulic acid, have been implicated in the mechanism behind this lower risk (Jonnalagadda et al., 2011). To date, this is an unexplored area for pet nutrition and additional studies are needed

Table 1. Nutrient analysis (mean ± SD) of brewers' rice and whole brown rice

Nutrient	Brown rice ($n = 17$)	Brewers' rice ($n = 17$)	P^1
Moisture, g/100 g	13.36 ± 0.81	12.74 ± 0.56	0.015
Ether extract, g/100 g DM	2.70 ± 0.78	0.96 ± 0.24	<0.001
Crude fiber, g/100 g DM	1.24 ± 0.30	0.50 ± 0.19	<0.001
Phosphorus, g/kg DM	3.25 ± 0.28	1.55 ± 0.40	<0.001
Potassium, g/kg DM	2.94 ± 0.22	1.48 ± 0.32	<0.001

[1]Independent t test.

The trend to include more whole ingredients in natural pet foods has also led to an increase in the inclusion of raw animal protein products as opposed to rendered animal protein products. Rendered products can have a wide range of nutritional variability, which is dependent on byproduct inclusion and processing of the product. For example, feed-grade poultry byproduct meal inclusive of feathers and heads had more variable nutrient content than pet-food grade poultry byproduct meal that did not contain feathers or heads (Dozier et al., 2003). In a study using roosters to measure true AA digestibility, rendered animal meals generally had lower AA digestibility than raw animal products, with lamb meal having the poorest AA digestibility and pork livers (raw animal product) having the greatest AA digestibility (Cramer et al., 2007). In a separate study, rendering of poultry, but not beef, seemed to have a slight negative influence on ileal, but not total tract, digestibility by dogs (Murray et al., 1997). It should be noted, however, that handling, processing, and preservation by an ingredient supplier is a large contributor to the variability in nutritional value of animal products (Parsons et al., 1997), and therefore ingredient supplier practices may be more important than ingredient type (i.e., raw vs. rendered) when assessing quality or nutritional value of animal products.

Ingredient and Product Processing

Processing can have either a positive or negative effect on nutritional value, depending on the processing method and outcomes measured. For example, the degree of gelatinization of wheat starch is positively associated with in vitro digestibility and plasma glucose and insulin responses in rats (Holm et al., 1988), indicating increased digestible carbohydrate bioavailability with processing. Additionally, starch gelatinization degree and reactive lysine in a canine diet increased with increasing extrusion temperatures up to 150°C compared to untreated control (Lankhorst et al., 2007). Conversely, increasing time of heat treatment during canning of cat food was associated with a decrease in true ileal AA digestibility in rats (Hendriks et al., 1999). Higher drying temperatures (200°C) of an extruded canine diet resulted

in lower lysine, reactive lysine, reactive to total lysine ratio, linolenic acid, and linoleic acid concentrations compared to lower drying temperatures (≤160°C) in 4 mm kibbles (Tran et al., 2011). These examples of processing influencing the quality and nutritional value of an ingredient or final product highlight the importance of quality control outcomes in ingredient selection and final product processing.

Processing method also influences nutritional value by affecting the moisture content of the final product. From a nutritional perspective, foods with moisture content similar to animal prey would better align with a natural pet nutrition philosophy compared to dry foods. While there is limited evidence to demonstrate a health benefit of high dietary moisture intake in dogs, there have been demonstrated effects in cats on urinary tract health and weight management. Feeding diets containing 73% moisture reduced ($P < 0.05$) the calcium oxalate relative super saturation from 1.14 ± 0.21 compared with the 6 (2.29 ± 0.21) and 53% (2.06 ± 0.21) moisture diets and reduced ($P < 0.001$) specific gravity from 1.036 ± 0.002 compared with the 6, 25, and 53% moisture diets (1.052–1.054 ± 0.002) while increasing ($P < 0.001$) total water intake of cats to 144.7 ± 5.2 mL compared with diets containing 6, 25, or 53% moisture (98.6–104.7 ± 5.3 mL; Buckley et al., 2011). Another study found that ad libitum ingestion of a 40% hydrated diet compared to a dry diet with 12% moisture following weight loss caused cats to eat less (77 ± 10.8 vs. 86 ± 18.4 g/d; $P < 0.05$), with a trend to gain less BW (312 ± 95.9 g vs. 368 ± 120.7 g; $P = 0.28$), and increased their activity level ($P < 0.001$; Cameron et al., 2011). Although these findings may be specific to the diets evaluated, given the ubiquitous nature of urinary related syndromes in cats, the potential health benefits of feeding pet food with higher moisture content (e.g., pasteurized/refrigerated, raw, frozen, or canned) that typically contain 70 to 85% moisture should be noted.

There are reports in the literature evaluating the digestibility of raw diets in feline species that have been discussed above. However, Kerr et al. (2012) evaluated the performance of extruded cat food versus a beef based diet fed either raw or cooked. These investigators found the apparent total tract digestibility to be greater ($P < 0.001$) in both the raw and cooked form of the beef based diet than the extruded diet. There were no differences in apparent digestibility between the raw and cooked beef based diet. The differences observed in this study could be due to the ingredient composition as well as processing method. Given the level of ingredient processing required before extrusion, it would be difficult to design a study using ingredients in the same physical form with and without extrusion.

Processing method is also an important influencer of food safety. With respect to food processing, unpasteurized raw foods would most closely match wild prey and therefore align with a natural pet nutrition philosophy. However, there are safety concerns with the pathogenic bacteria found in many raw meats. Studies have demonstrated that raw or undercooked animal-source protein may be contaminated with a variety of pathogenic organisms, including *Salmonella* spp., *Campylobacter* spp., *Clostridium* spp., *Escherichia coli*, *Listeria monocytogenes*, and enterotoxigenic *Staphylococcus aureus* (Freeman and Michel, 2001; LeJeune and Hancock, 2001; Joffe and Schlesinger, 2002; Stiver et al., 2003; Weese et al., 2005; Finley et al., 2006). In a cohort of 200 therapy dogs, the incidence rate of Salmonella shedding in the raw meat-fed dogs was 0.61 cases/dog–year, compared with 0.08 cases/dog–year in dogs that were not fed raw meat ($P < 0.001$; Lefebvre et al., 2008). This poses a risk of foodborne illness to the pets eating the contaminated food and of secondary transmission to humans, especially children, older persons, and immunocompromised individuals (LeJeune and Hancock, 2001; Joffe and Schlesinger, 2002). Given these health risks, the American Veterinary Medical Association, American Animal Hospital Association, and U.S. Food and Drug Administration have issued statements on the avoidance and safe handling practices of raw foods (AAHA, 2011; AVMA, 2012a; FDA, 2013). The American College of Veterinary Nutrition also has endorsed a publication on the potential risks vs. benefits of pets consuming raw meat based diets (Freeman et al., 2013). Furthermore, raw food diets can pose risk for metabolic disease depending on the parts of the animal used in the diet. For example, clinical cases of dietary hyperthyroidism have been reported in dogs fed bone and raw food diets, which was reversed by feeding commercial pet food (Kohler et al., 2012). To reduce safety concerns, minimal processing may be applied, such as pasteurization of raw animal products, or comprehensive microbiological testing of product may be used.

THE FUTURE OF NATURAL PET NUTRITION

The natural segment of manufactured pet food has grown in recent years driven by consumer demand. The increased demand for these products has centered on the consumer belief that these products are of high quality and safe, made from ingredients that fit an individual's concept of natural, and provide functional health benefits. Different regulatory definitions have been described by the AAFCO and FEDIAF for natural pet food ingredients and products; however, most consumers have their own perceptions of what should be considered natural based on personal experiences, biases, or preferences. In the absence of data on the impact of natural pet food on pet health, some pet food companies target diet formulation and ingredients based on teleological reasoning that

dogs and cats should eat a diet resembling that of related wild species. Many opportunities exist for research involving natural pet foods and natural diets to understand their effects on growth and performance, nutrient availability, digestibility, and product safety among other health and nutrition parameters. Future opportunities also include the integration of sustainability with natural pet foods (Swanson et al., 2013). The challenge is to match consumer demand and provide natural nutrition to pets while reducing impact on the environment. With the increasing trend of anthropomorphism of pets and interest in ancestral or instinctual diets, challenges of particular interest to the natural pet food segment include competition with the human food chain and the high use of animal protein sources.

LITERATURE CITED

American Animal Hospital Association (AAHA). 2011. Raw protein diet position statement. www.aahanet.org/Library/Raw_Food_Diet.aspx. (Accessed November 4, 2013.)

American Veterinary Medical Association (AVMA). 2012a. Raw or undercooked animal-source protein in cat and dog diets. www.avma.org/KB/Policies/Pages/Raw-or-Undercooked-Animal-Source-Protein-in-Cat-and-Dog-Diets.aspx. (Accessed November 4, 2013.)

American Veterinary Medical Association (AVMA). 2012b. U.S. pet ownership & demographics sourcebook. AVMA, Schaumburg IL.

Association of American Feed Control Officials (AAFCO). 2013. Official Publication. Assoc. Am. Feed Cont. Off., Champaign, IL.

Axelsson, E., A. Ratnakumar, M. L. Arendt, K. Maqbool, M. T. Webster, M. Perloski, O. Liberg, J. M. Arnemo, A. Hedhammar, and K. Lindblad-Toh. 2013. The genomic signature of dog domestication reveals adaptation to a starch-rich diet. Nature 495:360–364.

Bahadoran, Z., M. Golzarand, P. Mirmiran, A. Amouzgar, and F. Azizi. 2012. Association between dietary phytochemical index and occurrence of metabolic syndrome and its risk factors (among Tehranian adults): Tehran lipid and glucose study. Iran. J. Endocrinol. Metab. 14:343–352.

Barnard, N. D. 2010. Trends in food availability, 1909–2007 1–3. Am. J. Clin. Nutr. 91:1530S–1536S.

Bauer, J. E. 2006. Facilitative and functional fats in diets of cats and dogs. J. Am. Vet. Med. Assoc. 229:680–684.

Blanchard, G., P. Nguyen, C. Gayet, I. Leriche, B. Siliart, and B. M. Paragon. 2004. Rapid weight loss with a high-protein low-energy diet allows the recovery of ideal body composition and insulin sensitivity in obese dogs. J. Nutr. 134:2148S–2150S.

Boitani, L., and P. Ciucci. 1995. Comparative social ecology of feral dogs and wolves. Ethol. Ecol. Evol. 7:49–72.

Buckley, C. M., A. Hawthorne, A. Colyer, and A. E. Stevenson. 2011. Effect of dietary water intake on urinary output, specific gravity and relative supersaturation for calcium oxalate and struvite in the cat. Br. J. Nutr. 106(Suppl. 1):S128–S130.

Cameron, K. M., P. J. Morris, R. M. Hackett, and J. R. Speakman. 2011. The effects of increasing water content to reduce the energy density of the diet on body mass changes following caloric restriction in domestic cats. J. Anim. Physiol. Anim. Nutr. (Berl.) 95:399–408.

Carciofi, A. C., F. S. Takakura, L. D. de-Oliveira, E. Teshima, J. T. Jeremias, M. A. Brunetto, and F. Prada. 2008. Effects of six carbohydrate sources on dog diet digestibility and post-prandial glucose and insulin response. J. Anim. Physiol. Anim. Nutr. (Berl.) 92:326–336.

Clutton-Brock, J. 1995. Origins of the dog: Domestication and early history. In: J. Serpell, editor, The domestic dog: Its evolution, behaviour and interactions with people. Cambridge Univ. Press, New York. p. 7–20.

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

de Godoy, M. R. C., K. R. Kerr, and G. C. Fahey Jr. 2013. Alternative dietary fiber sources in companion animal nutrition. Nutrients 5:3099–3117.

Diez, M., P. Nguyen, I. Jeusette, C. Devois, L. Istasse, and V. Biourge. 2002. Weight loss in obese dogs: Evaluation of a high-protein, low-carbohydrate diet. J. Nutr. 132:1685S–1687S.

Downey, R. L., D. S. Kronfeld, and C. A. Banta. 1980. Diet of beagles affects stamina. J. Am. Anim. Hosp. Assoc. 16:273–277.

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

Elliott, K. F., J. S. Rand, L. M. Fleeman, J. M. Morton, A. L. Litster, V. C. Biourge, and P. J. Markwell. 2012. A diet lower in digestible carbohydrate results in lower postprandial glucose concentrations compared with a traditional canine diabetes diet and an adult maintenance diet in healthy dogs. Res. Vet. Sci. 93:288–295.

The European Pet Food Industry Federation (FEDIAF). 2011. Code of good labelling practices for pet food. Euro. Pet Food Ind. Fed., Brussels, Belgium.

Ewer, R. F. 1973. The carnivores, the world naturalist. Weidenfeld and Nicolson, London, UK.

Farrow, H. A., J. S. Rand, and G. D. Sunvold. 2002. The effect of high protein, high fat or high carbohydrate diets on postprandial glucose and insulin concentrations in normal cats. J. Vet. Intern. Med. 16:360.

Finley, R., R. Reid-Smith, and J. S. Weese. 2006. Human health implications of Salmonella-contaminated natural pet treats and raw pet food. Clin. Infect. Dis. 42:686–691.

Forster, G. M., D. Hill, G. Gregory, K. M. Weishaar, S. Lana, J. E. Bauer, and E. P. Ryan. 2012a. Effects of cooked navy bean powder on apparent total tract nutrient digestibility and safety in healthy adult dogs. J. Sci. 90:2631–2638.

Forster, G. M., C. A. Ollila, J. H. Burton, D. Hill, J. E. Bauer, A. M. Hess, and E. P. Ryan. 2012b. Nutritional weight loss therapy with cooked bean powders regulates serum lipids and biochemical analytes in overweight and obese dogs. J. Obes. Wt. Loss. Ther. 2:8.

Freeman, L. M., M. L. Chandler, B. A. Hamper, and L. P. Weeth. 2013. Current knowledge about the risks and benefits of raw meat-based diets for dogs and cats. J. Am. Vet. Med. Assoc. 243:1549–1558

Freeman, L. M., and K. E. Michel. 2001. Evaluation of raw food diets for dogs. J. Am. Vet. Med. Assoc. 218:705–709.

German, A. J., S. L. Holden, T. Bissot, P. J. Morris, and V. Biourge. 2010. A high protein high fibre diet improves weight loss in obese dogs. Vet. J. 183:294–297.

Griffiths, T. 2010. Promoting cereal grain and whole grain consumption: An Australian perspective. Cereal Chem. 87:159–161.

Hemmer, H. 1990. Domestication: The decline of environmental appreciation. 2nd ed. Cambridge Univ. Press, New York.

Hendriks, W. H. 2013. The nature of canine and feline nutrition. In: The WALTHAM International Nutritional Sciences Symposium, Portland, OR. p. 21–22.

Hendriks, W. H., M. M. Emmens, B. Trass, and J. R. Pluske. 1999. Heat processing changes the protein quality of canned cat foods as measured with a rat bioassay. J. Anim. Sci. 77:669–676.

Hewson-Hughes, A. K., V. L. Hewson-Hughes, A. Colyer, A. T. Miller, S. J. McGrane, S. R. Hall, R. F. Butterwick, S. J. Simpson, and D. Raubenheimer. 2013. Geometric analysis of macronutrient selection in breeds of the domestic dog, *Canis lupus familiaris*. Behav. Ecol. 24:293–304.

Hewson-Hughes, A. K., V. L. Hewson-Hughes, A. T. Miller, S. R. Hall, S. J. Simpson, and D. Raubenheimer. 2011. Geometric analysis of macronutrient selection in the adult domestic cat, *Felis catus*. J. Exp. Biol. 214:1039–1051.

Hill, R. C., D. D. Lewis, K. C. Scott, M. Omori, M. Jackson, D. A. Sundstrom, G. L. Jones, J. R. Speakman, C. A. Doyle, and R. F. Butterwick. 2001. Effect of increased dietary protein and decreased dietary carbohydrate on performance and body composition in racing Greyhounds. Am. J. Vet. Res. 62:440–447.

Hill, S. R., K. J. Rutherfurd-Markwick, G. Ravindran, C. E. Ugarte, and D. G. Thomas. 2009. The effects of the proportions of dietary macronutrients on the digestibility, post-prandial endocrine responses and large intestinal fermentation of carbohydrate in working dogs. N. Z. Vet. J. 57:313–318.

Hoenig, M., K. Thomaseth, M. Waldron, and D. C. Ferguson. 2007. Insulin sensitivity, fat distribution, and adipocytokine response to different diets in lean and obese cats before and after weight loss. Am. J. Physiol. Regul. Integr. Comp. Physiol. 292:R227–R234.

Holm, J., I. Lundquist, I. Bjorck, A. C. Eliasson, and N. G. Asp. 1988. Degree of starch gelatinization, digestion rate of starch in vitro, and metabolic response in rats. Am. J. Clin. Nutr. 47:1010–1016.

Hore, P., and M. Messer. 1968. Studies on disaccharidase activities of the small intestine of the domestic cat and other carnivorous mammals. Comp. Biochem. Physiol. 24:717–725.

Jacobs, D. R., Jr., M. D. Gross, and L. C. Tapsell. 2009. Food synergy: An operational concept for understanding nutrition. Am. J. Clin. Nutr. 89:1543S–1548S.

Joffe, D. J., and D. P. Schlesinger. 2002. Preliminary assessment of the risk of Salmonella infection in dogs fed raw chicken diets. Can. Vet. J. 43:441–442.

Johnson, W. E., and S. J. O'Brien. 1997. Phylogenetic reconstruction of the Felidae using 16S rRNA and NADH-5 mitochondrial genes. J. Mol. Evol. 44(Suppl. 1):S98–S116.

Jonnalagadda, S. S., L. Harnack, R. H. Liu, N. McKeown, C. Seal, S. Liu, and G. C. Fahey. 2011. Putting the whole grain puzzle together: Health benefits associated with whole grains–summary of American Society for Nutrition 2010 Satellite Symposium. J. Nutr. 141:1011S–1022S.

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

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

Kienzle, E. 1993a. Carbohydrate metabolism of the cat 1. Activity of amylase in the gastrointestinal tract of the cat. J. Anim. Physiol. Anim. Nutr. (Berl.) 69:92–101.

Kienzle, E. 1993b. Carbohydrate metabolism of the cat 2. Digestion of starch. J. Anim. Physiol. Anim. Nutr. (Berl.) 69:102–114.

Kienzle, E. 1993c. Carbohydrate metabolism of the cat. 3. Digestion of sugars. J. Anim. Physiol. Anim. Nutr. (Berl.) 69:203–210.

Kienzle, E. 1993d. Carbohydrate metabolism of the cat. 4. Activity of maltase, isomaltase, sucrase and lactase in the gastrointestinal tract in relation to age and diet. J. Anim. Physiol. Anim. Nutr. (Berl.) 70:89–96.

Kienzle, E. 1994. Effect of carbohydrates on digestion in the cat. J. Nutr. 124:2568S–2571S.

Kohler, B., C. Stengel, and R. Neiger. 2012. Dietary hyperthyroidism in dogs. J. Small Anim. Pract. 53:182–184.

Kronfeld, D. S., P. L. Ferrante, and D. Grandjean. 1994. Optimal nutrition for athletic performance, with emphasis on fat adaptation in dogs and horses. J. Nutr. 124:2745S–2753S.

Lankhorst, C., Q. D. Tran, R. Havenaar, W. H. Hendriks, and A. F. B. van der Poel. 2007. The effect of extrusion on the nutritional value of canine diets as assessed by in vitro indicators. Anim. Feed Sci. Technol. 138:285–297.

Lefebvre, S. L., R. Reid-Smith, P. Boerlin, and J. S. Weese. 2008. Evaluation of the risks of shedding Salmonellae and other potential pathogens by therapy dogs fed raw diets in Ontario and Alberta. Zoonoses Public Health 55:470–480.

LeJeune, J. T., and D. D. Hancock. 2001. Public health concerns associated with feeding raw meat diets to dogs. J. Am. Vet. Med. Assoc. 219:1222–1225.

Leray, V., B. Siliart, H. Dumon, L. Martin, R. Sergheraert, V. Biourge, and P. Nguyen. 2006. Protein intake does not affect insulin sensitivity in normal weight cats. J. Nutr. 136:2028S–2030S.

Liu, R. H., J. Liu, and B. Chen. 2005. Apples prevent mammary tumors in rats. J. Agric. Food Chem. 53:2341–2343.

Liu, S., J. E. Manson, I. M. Lee, S. R. Cole, C. H. Hennekens, W. C. Willett, and J. E. Buring. 2000. Fruit and vegetable intake and risk of cardiovascular disease: The Women's Health Study. Am. J. Clin. Nutr. 72:922–928.

Lummis, D. 2012. Natural, organic and eco-friendly pet products in the U.S. Packaged Facts, Rockville, MD.

Lund, E. M., P. J. Armstrong, C. A. Kirk, and J. S. Klausner. 2005. Prevalence and risk factors for obesity in adult cats from private US veterinary practices. Int. J. Appl. Res. Vet. Med. 3:88–96.

Lund, E. M., P. J. Armstrong, C. A. Kirk, and J. S. Klausner. 2006. Prevalence and risk factors for obesity in adult dogs from private US veterinary practices. Int. J. Appl. Res. Vet. Med. 4:177–186.

McClelland, G., G. Zwingelstein, C. R. Taylor, and J. M. Weber. 1994. Increased capacity for circulatory fatty acid transport in a highly aerobic mammal. Am. J. Physiol. 266:R1280–R1286.

Mirmiran, P., Z. Bahadoran, M. Golzarand, N. Shiva, and F. Azizi. 2012. Association between dietary phytochemical index and 3-year changes in weight, waist circumference and body adiposity index in adults: Tehran Lipid and Glucose study. Nutr. Metab. (Lond.) 9:108.

Morris, J. G., J. Trudell, and T. Pencovic. 1977. Carbohydrate digestion by the domestic cat (*Felis catus*). Br. J. Nutr. 37:365–373.

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

Nguyen, P., H. Dumon, V. Biourge, and E. Pouteau. 1998. Glycemic and insulinemic responses after ingestion of commercial foods in healthy dogs: Influence of food composition. J. Nutr. 128:2654S–2658S.

NRC. 2006. Nutrient requirements of dogs and cats. The National Academies Press, Washington, DC.

Okarter, N., and R. H. Liu. 2010. Health benefits of whole grain phytochemicals. Crit. Rev. Food Sci. Nutr. 50:193–208.

Parsons, C. M., F. Castanon, and Y. Han. 1997. Protein and amino acid quality of meat and bone meal. Poult. Sci. 76:361–368.

Plantinga, E. A., G. Bosch, and W. H. Hendriks. 2011. Estimation of the dietary nutrient profile of free-roaming feral cats: Possible implications for nutrition of domestic cats. Br. J. Nutr. 106(Suppl. 1):S35–S48.

Reijnders, L., and S. Soret. 2003. Quantification of the environmental impact of different dietary protein choices. Am. J. Clin. Nutr. 78:664S–668S.

Reynolds, A. J., L. Fuhrer, H. L. Dunlap, M. Finke, and F. A. Kallfelz. 1995. Effect of diet and training on muscle glycogen storage and utilization in sled dogs. J. Appl. Physiol. 79:1601–1607.

Seeram, N. P., L. S. Adams, S. M. Henning, Y. Niu, Y. Zhang, M. G. Nair, and D. Heber. 2005. In vitro antiproliferative, apoptotic and antioxidant activities of punicalagin, ellagic acid and a total pomegranate tannin extract are enhanced in combination with other polyphenols as found in pomegranate juice. J. Nutr. Biochem. 16:360–367.

Serpell, J. 1995. The domestic dog: Its evolution, behaviour and interactions with people. Cambridge Univ. Press, New York.

Serpell, J. 2000. Domestication and history of the cat. In: D. C. Turner and P. Bateson, editors, The domestic cat: The biology of its behaviour. Cambridge Univ. Press, New York. p. 179–192.

Shmalberg, J. 2013. Novel trends in small animal nutrition: A practical guide. Today's Vet. Pract. 3:38–45.

Smithers, R. H. N. 1968. Cat of the pharaohs. Anim. Kingdom 61:16–23.

Stahler, D. R., D. W. Smith, and D. S. Guernsey. 2006. Foraging and feeding ecology of the gray wolf (*Canis lupus*): Lessons from Yellowstone National Park, Wyoming, USA. J. Nutr. 136:1923S–1926S.

Stiver, S. L., K. S. Frazier, M. J. Mauel, and E. L. Styer. 2003. Septicemic salmonellosis in two cats fed a raw-meat diet. J. Am. Anim. Hosp. Assoc. 39:538–542.

Swanson, K. S., R. A. Carter, T. P. Yount, J. Aretz, and P. R. Buff. 2013. Nutritional sustainability of pet foods. Adv. Nutr. 4:141–150.

Tanaka, A., A. Inoue, A. Takeguchi, T. Washizu, M. Bonkobara, and T. Arai. 2005. Comparison of expression of glucokinase gene and activities of enzymes related to glucose metabolism in livers between dog and cat. Vet. Res. Commun. 29:477–485.

Thiess, S., C. Becskei, K. Tomsa, T. A. Lutz, and M. Wanner. 2004. Effects of high carbohydrate and high fat diet on plasma metabolite levels and on i.v. glucose tolerance test in intact and neutered male cats. J. Feline Med. Surg. 6:207–218.

Tiwari, U., and E. Cummins. 2013. Factors influencing levels of phytochemicals in selected fruit and vegetables during pre- and postharvest food processing operations. Food Res. Int. 50:497–506.

Tran, Q. D., W. H. Hendriks, and A. F. B. van der Poel. 2011. Effects of drying temperature and time of a canine diet extruded with a 4 or 8 mm die on physical and nutritional quality indicators. Anim. Feed Sci. Technol. 165:258–264.

U.S. Food and Drug Administration (FDA). 2013. Get the facts! Raw pet food diets can be dangerous to you and your pet. www.fda.gov/AnimalVeterinary/ResourcesforYou/AnimalHealthLiteracy/ucm373757.htm. (Accessed November 20, 2013.)

Verbrugghe, A., M. Hesta, S. Daminet, and G. P. Janssens. 2012. Nutritional modulation of insulin resistance in the true carnivorous cat: A review. Crit. Rev. Food Sci. Nutr. 52:172–182.

Verbrugghe, A., M. Hesta, S. Van Weyenberg, G. A. Papadopoulos, K. Gommeren, S. Daminet, T. Bosmans, I. Polis, J. Buyse, and G. P. Janssens. 2010. The glucose and insulin response to isoenergetic reduction of dietary energy sources in a true carnivore: The domestic cat (*Felis catus*). Br. J. Nutr. 104:214–221.

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

Washizu, T., A. Tanaka, T. Sako, M. Washizu, and T. Arai. 1999. Comparison of the activities of enzymes related to glycolysis and gluconeogenesis in the liver of dogs and cats. Res. Vet. Sci. 67:205–206.

Weese, J. S., J. Rousseau, and L. Arroyo. 2005. Bacteriological evaluation of commercial canine and feline raw diets. Can. Vet. J. 46:513–516.